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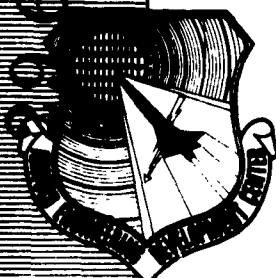
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# ION GAUGE CHARACTERISTICS IN AN AEROSPACE SIMULATOR

By

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Schenectady, New York

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**General Engineering Laboratory**

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**February 1963**

### FOREWORD

The work described in this report was performed at the General Engineering Laboratory, General Electric Company for the Missile and Space Vehicle Department, General Electric Company in partial fulfillment of Government Contract Number AF 40(600)-954.

**ABSTRACT**

The purpose of this investigation was to determine the relationship of ion gauge readings to the fundamental gas properties of pressure, density, and molecular incidence rate, and to study a modification of the ion gauge for use in space simulators where directional pressures exist because of large cryogenically-cooled pumping areas.

A theoretical analysis of the operation of the ion gauge suggested that a nude gauge senses the density of gas in a vacuum chamber, whereas a tubulated gauge senses the amount of molecular flux incident on the mouth of the tubulation; neither gauge actually measures pressure. Experiments were then conducted with specially constructed gauges in a vacuum system where the gas parameters could be varied individually to check the validity of the analysis. The predicted behavior was obtained with both nitrogen and helium, although some anomalous results were seen in the latter case.

The modified ion gauge, also known as the Space Simulation Gauge, is a tubulated gauge incorporating a cryogenic pumping surface to reduce the response to the incident flux of condensible molecules as if the flux were reflected from the wall of the space chamber having cryogenic pumping panels. A means of calculating the proper pumping area within the gauge was developed and applied. The ability to produce the intended reduction in sensitivity was experimentally confirmed, and some effects of gauge geometry were explored.

**PUBLICATION REVIEW**

This report has been reviewed and publication is approved.



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## 1.0 INTRODUCTION

As a necessary consequence of the space age, it has become mandatory to plan for ground testing of space vehicles, components and materials. The duplication of all the spatial environments is obviously impossible. Many papers have been written defining those environments which could be simulated and the degree to which simulation is required. Among those listed as necessary and feasible is the low pressure environment of outer space. It is frequently stated that a pressure of  $10^{-5}$  torr is sufficient to simulate the thermal radiation environment and the high electrical impedance of space. This statement alone does not define where the pressure is measured, nor in fact what is meant by pressure in the highly directional conditions of both true space and a space environmental simulator. A serious evaluation of the nature of the molecular flux in both cases is necessary in order to evaluate what is meant by simulation.

### 1.1 THE VEHICLE IN SPACE

Two altogether different gaseous sources surround the vehicle in space. First, there is the natural environment which was there prior to the entry of the space vehicle, and secondly, the gas sources which have been contributed by the vehicle.

The atmosphere of the planet earth at altitudes above 1500 km consists primarily of hydrogen ions, decreasing in density with increase in altitude. Below this level, the atmosphere consists principally of oxygen and nitrogen in atomic, ionized, or molecular states, depending on the altitude. Between 200 and 1500 km the density decreases with increasing altitude from about  $10^{10}$  to  $10^5$  particles per cubic centimeter. The corresponding mean free paths range from a few miles to several hundred thousand miles, distances which are huge relative to the dimensions of any space craft. The velocity of these molecules ranges from 1 to 2 km/sec. Yet, the velocity of an earth satellite ranges from 7.5 to 11 km/sec. The vehicle then appears to be rushing through a relatively stationary low density gas medium, most of the collisions being on the leading edge of the space craft. We note then that the molecular incidence rate, and the pressure, depends on the velocity of the vehicle and varies over the surface of the vehicle.

In addition to the planet atmosphere, the sun is thought to emit a variable stream of protons and electrons (solar wind) having a density of 600 to 10,000 protons per cubic centimeter near the earth. The velocity of these protons varies from 500 to 2000 km/sec. depending on the solar activity. The incidence rate is from  $5 \times 10^{10}$  to  $2 \times 10^{12}$  particles per second per square centimeter, which is comparable to the incidence rate of molecules from the planet atmosphere at high altitudes. Since the velocity of the solar wind is so much higher than that of the vehicle, the collisions are all on the side facing the sun. The extremely high energy is sufficient to cause sputtering or other surface phenomena. Again we note that there is no uniformity over the surface of the vehicle, nor can we simply define a pressure equivalent of altitude.

In addition to the environmental gases, the vehicle itself is a major source of gas, in the form of outgassing and leakage. This gas is given off by the vehicle with thermal energies relative to the vehicle. The outgassing occurs in all directions, but may well vary over the surface of the vehicle, depending on the variations in the vehicle structure and material composition. The outgassing products will travel many miles in a straight line before making collisions with an environmental molecule, hence for all practical purposes, the molecules which leave the vehicle are permanently

gone. Space may therefore be considered as pumping molecules as fast as they are produced. This pumping action is not related to the conventional concept of effusion velocity of an orifice of a fixed speed per unit area, as no fixed area of space can be defined as the pumping surface.

In almost all space vehicle situations, the outgassing of the vehicle represents a far greater density than that contributed by either the planet environment or the solar wind. Hence, the gas density surrounding the vehicle is almost entirely made up of the composition of the outgassing products. Yet this gas is all moving away from the vehicle and does not contribute to the gas returning to the vehicle. The returning gas is still defined by the velocity of the vehicle and the normal environment through which it is moving.

## 1.2 THE VEHICLE IN A CHAMBER

When a vehicle is placed in a space simulation chamber, it is again exposed to two different sources of gas: 1) the natural environment or background of the chamber, and 2) the gas contributions due to the outgassing and leakage of the vehicle.

For true duplication of the atmosphere of space, the chamber background should match that of the upper atmosphere in gas type, density and energy. In addition it should be properly oriented to account for the relative velocity of the vehicle through the stationary gas, and the solar wind. While such conditions are not completely impossible, they are sufficiently difficult and expensive that realistic evaluations are required to determine the necessity of such duplication. In the normal space chamber, the residual gas is made up of the outgassing products of the walls of the chamber and leaks which may exist to the outside atmosphere or to various internal fluid sections such as cryogenic lines. The composition of this gas will vary in different chambers, and may include such gas types as: water vapor, hydrogen, carbon dioxide, carbon monoxide, nitrogen and helium. The gas is not ionized, and in general is at a temperature of about 100°K. In addition there may be directional effects in the event that discontinuities exist on the chamber wall. For example, the presence of a large area solar simulator may contribute a high outgassing rate from a particular section of the chamber wall.

When the vehicle is in a chamber, just as when it is in space, the outgassing of the vehicle is the predominate gas present. However, in the case of the chamber an altogether different situation exists. In order to duplicate the effectively infinite pumping speed of outer space the chamber must have walls which are perfect condensers for all incident molecules. Since such perfect condensers are not presently feasible, a great majority of the outgassing from the vehicle is reflected from the chamber wall and returns to the vehicle. In almost all instances, this returning gas flux is far larger than the original chamber background. Again we note that this gas flux does not have the characteristic properties of the permanent space background. The gas is predominately water and nitrogen. The temperature is between 100 and 300°K. Anomalous directional effects may exist if large areas of non pumping walls are present.

The foregoing differences between a chamber and space may not be of importance in the superficial condition of simulating for heat transfer and electrical discharge effects. However, if any surface phenomena is involved, such as friction or sputtering, entirely different results may be obtained in the two cases.

### 1.3 MOLECULAR KINETICS

Considering the foregoing differences between true space and so called space simulators, it is apparent the simple question "What altitude has been simulated?" is almost impossible to define. In the simplest case it creates a serious controversy of philosophy, measuring equipment, and people. The purpose of the Molecular Kinetics program was to compare the various gas-vehicle collisions in space and in a chamber, to produce a yardstick for measuring simulation, and to define the effects or limitations of various chamber parameters on the degree of simulation achieved. This program is divided into a number of different phases, each covered in a different report. The common denominator of all phases of the Molecular Kinetics program, is the dealing with highly directional gas flows in terms of measuring, controlling, or defining simulation.

In order to derive a language to be used in the interpretation of space simulation, and which is compatible with the parameters present in space simulators, it is first necessary to define the ground rules to be used. We first note that the vehicle is the point of interest for discussing simulation, and further it is the molecules arriving at the vehicle which are of importance. Any measurement or consideration of molecular fluxes or pressures on the chamber wall are of importance only in so far as they can be interpreted at the vehicle proper. The second important factor to be determined is the term to be used for discussing gas particles in the simulator. Three different terms are immediately apparent: pressure, density and particle flux.

While density is very meaningful for the random gas in space in the absence of a vehicle, it has little meaning for the vehicle when a large amount of outgassing products from the vehicle are included in the measurement. The density concept does not define the direction of the gas and hence cannot be related to the molecules striking the vehicle, either in space or in a chamber.

A consideration of the earlier discussions on the extreme directional effects both in space and in a chamber indicates that molecular incidence and energy level are the important factors in assessing simulation. It is apparent that there is a considerable difference in the temperatures, i.e. energy levels, in space and in a simulator. A theoretical assessment of the temperature of the molecules received by the vehicle in a space chamber is almost impossible due to the variations in the temperature within the chamber and the differences in the accommodation coefficient for different gases. While pressure is related to both energy and incidence rate, the true measurement of pressure is likewise a very difficult problem. From the point of view of both analysis and measurement techniques, it is far easier to consider the rate at which molecules are striking a surface. Except for cases of extreme energy (such as the solar wind) the surface reactions are more dependent on the gas type than on the variations of energy which exist. For these, and other reasons which will be more apparent in the different reports, the concept of molecular flux has been chosen for all analysis. Molecular flux is defined as the number of molecules per unit area per unit time incident upon or leaving a given surface.

### 1.4 MEASUREMENT OF VACUUM SIMULATION

The measurement of pressure in vacuum systems, or more precisely the measurement of the degree of vacuum, is commonly made by the use of ion gauges. Although there are many types of ion gauges, all indicate the degree of vacuum by measuring

the number of ions created in the residual gas by a stream of ionizing particles. These gauges do not sense in any way the force of impinging gas molecules on a surface and hence are not true pressure gauges. Notwithstanding this fact, the readings are nearly always reported in terms of pressure and for many purposes this interpretation is apparently satisfactory.

In a space simulation chamber, however, the meaning of pressure is ambiguous because of the directional gas flow. The pressure of the impacting molecules on the wall is grossly different from that on the vehicle and the "pressure" on the vehicle due to the momentum of the molecules leaving in the form of outgassing is not even considered. Further, as has been stated above, unless the energy of impacting molecules is very high, the number of such molecules is more important than the energy level. Thus the magnitude of the molecular flux impinging on the vehicle is a more significant criterion of the degree of space simulation than the pressure created by this flux.

Fortunately, it can be reasoned that conventional ion gauges respond according to molecular flux. Basically, an ion gauge produces a current which is proportional to the number of gas molecules within the ionizing region of the gauge, the constant of proportionality being dependent on the gas type. Based on this property and the exchange of gas molecules between the gauge and the chamber, the relationship between the vacuum conditions in the chamber and the number of molecules in the gauge can be derived. Molecules from the chamber enter the gauge at a rate proportional to the molecular flux on the mouth of the gauge tubulation. Molecules in turn leave the gauge at a rate proportional to the number of molecules in the gauge and their velocities. Assuming that the gauge is neither outgassing nor pumping at a significant rate, the density in the gauge varies in proportion to the molecular flux on the gauge in such a manner that the amounts of gas entering and leaving the gauge are equal. The temperature of the incident gas molecules is immaterial because this energy is exchanged with the walls of the gauge and its tubulation.

Having a gauge which measures molecular flux, it should next be pointed out that it is the flux falling on the vehicle which must be measured. The obvious way of making such a measurement is to place the gauge adjacent to or on the vehicle, with the mouth of the tubulation facing the wall of the chamber. In many cases, practical considerations such as the bringing out of the electrical leads or temperature effects of the gauge filament may preclude such mounting. A means of using a wall-mounted gauge to measure the flux on the vehicle is therefore desirable. It is possible to produce this effect in a gauge by the deliberate inclusion of pumping surfaces within the gauge to simulate the pumping effects in the chamber.

## 2.0 ION GAUGE CHARACTERISTICS

In order to make measurements of high or ultra-high vacuums, the use of an ionizing type gauge is almost mandatory. In vacuum technology, these gauges are said to be pressure gauges, although there is no direct sensing of pressure in the gauge. A more precise analysis of the gauge behavior is made below, with the object of defining what gas property is actually measured. This theoretical study is supplemented by experimental tests in which the parameters pressure, temperature, density, and molecular flux were investigated. It is shown that "nude" gauges respond to molecular density, whereas tubulated gauges respond to molecular flux.

### 2.1 THEORETICAL ANALYSIS

An analysis of ion gauge behavior can be made on the basis of a fundamental postulate, namely, for a given gas type, the reading of the gauge is proportional to the number of molecules in the ionizing zone of the gauge. There are some basic questions about the accuracy of this postulate. In the first place, in the normal operating range of an ion gauge, the electrons are far more likely to collide with molecules adsorbed on the grid than with molecules in the gas phase, assuming that the grid is covered with at least one monomolecular layer of gas. Yet much evidence points to the conclusion that nearly all the measured ions are formed in the gas phase. For example, the number of adsorbed molecules can be drastically altered by heating the grid, with relatively small changes in the reading of the gauge. Secondly, it must be assumed that the trajectories of the ionizing electrons do not change with time due to nonuniform deterioration of the filament or change in its position or any other reason. Thirdly, it is possible to develop insulating coatings on the ion collection electrode due to operation in a contaminated atmosphere which reduce the collection efficiency. In the following, however, it will be assumed that the gauge operates in the intended fashion; the ion current per unit electron emission is proportional to the number density of gas molecules (molecular density) in the gauge.

Having said this, it is necessary to point out that the molecular density in the gauge is in general different from that in the vacuum chamber to which the gauge is attached except in the case of nude gauges where the vacuum chamber is also the envelope of the gauge. Such is obviously the case where the gauge is outgassing at a high rate relative to the rate of exhaust through its tubulation. Gauges have also been reported to pump, particularly when they have just previously been heated to reduce the outgassing rate. The pumping action is known to be of at least two types, chemical and electronic, with speeds of about 2 liters/sec and .25 liters/sec, respectively<sup>(1)</sup>. There is probably a third type of pumping, due to physical adsorption, with a pumping speed of 10 or more liters per second, which is present in a freshly degassed gauge under some conditions. These speeds are dependent on the gas type. Fortunately, the pumping actions become saturated eventually, so that an equilibrium is reached. Redhead states that chemical pumping of nitrogen ceases after about  $10^{15}$  molecules are pumped and electronic pumping of nitrogen persists until about  $10^{17}$  molecules are pumped.<sup>(1)</sup> The time to reach these levels will depend on the pressure, and may be appreciable at very low pressures; for example, at  $10^{-9}$  torr chemical pumping will persist for 4 to 5 hours in a typical tubulated gauge according to the above data.

Assuming that means of mitigating the spurious effects above are employed so that the readings of the gauge are not materially affected, the relationship of the gauge readings to the vacuum chamber conditions may be analyzed as follows. There will be a constant interchange of gas molecules between the gauge and the vacuum chamber, but no significant net flow. Gas molecules are assumed to follow random paths in this interchange, the trajectories of such molecules being independent of their velocities. The rate of escape of molecules from the gauge will therefore be proportional to the number of molecules in the gauge and their average velocity.

$$\dot{n}_{out} = K_1 n_g v_g = K_1 n_g \sqrt{\frac{2\pi M}{RT_g}} \quad 1)$$

where  $\dot{n}_{out}$  = rate of escape of molecules from gauge

$K_1$  = a constant

$n_g$  = number density of molecules in gauge

$v_g$  = average velocity of molecules in gauge

$T_g$  = average temperature of molecules in gauge

The rate at which molecules enter the gauge will be proportional to the number of molecules incident on the mouth of the gauge tubulation and the probability that such an incident molecule will enter the gauge, a quantity which is dependent somewhat on the directional characteristics of this flux.

$$\dot{n}_{in} = K_2 \phi_c \quad 2)$$

where  $\dot{n}_{in}$  = rate entry of molecules into gauge

$K_2$  = a constant

$\phi_c$  = flux (incident rate) of molecules on mouth of gauge

Since there is no net flow, the number escaping must be equal to the number entering and therefore the molecular density of molecules inside the tubulated gauge is related to the flux of molecules on the mouth of the tubulation according to the equation.

$$\phi_c = K n_g \sqrt{\frac{M}{T_s}} \quad 3)$$

The significance of equation 3) is of interest. It states that the molecular density in the gauge depends on the incident flux, the molecular weight of the gas, and the temperature of the gas in the gauge. Because of the long mean free paths in the gas, all molecules in the gauge make frequent collisions with the gauge walls and tend to assume the wall temperature immediately on entering the gauge. Thus the temperature in equation 3) is that of the gauge and is independent of the temperature of the attached vacuum chamber. It follows that with a

fixed gauge temperature and a given gas type, the reading of a tubulated gauge is directly proportional to the molecular flux incident upon it. In a nude gauge, on the other hand, the density is the same as that in the vacuum space and for a given gas type the reading is proportional to the molecular density. These relationships are expressed by the following equations:

for a tubulated gauge

$$R = \frac{S}{K} \sqrt{\frac{T_s}{M}} \phi_c$$

for a nude gauge

$$R = S n_c$$

where  $R$  = the gauge reading per unit emission

$S$  = the gauge sensitivity for the gas type

$n_c$  = the molecular density in the vacuum chamber

## 2.2 EXPERIMENTAL STUDY

As a check on the above analysis, measurements were made with ion gauges in a vacuum system. The vacuum system was modified to enable the effects of pressure, temperature, density, and molecular flux to be evaluated separately. Special test gauges were also constructed. In succeeding paragraphs descriptions will be given of the vacuum system, the gauges, and the experimental techniques used.

### 2.2.1 Vacuum System

A dynamic vacuum system was used for studying ion gauge characteristics; that is, a continuous bleed of gas was introduced into the system at a controlled rate, while pumping simultaneously through an orifice of constant speed. Random gas flow in the gauge chamber was provided by facing the outlet of the leak away from the gauges, and by sizing the system so that molecules make an average of several thousand bounces before being pumped out. The system was operated at pressures sufficiently low (in the  $10^{-5}$  torr range) that free molecular flow prevailed. A photograph of the system is shown in Figure 1.

The properties of the particular arrangement used are as follows:

- 1) At a fixed gas inlet rate, the molecular incidence rate on any given part of the chamber is independent of temperature or gas type. This conclusion follows from the consideration that the molecular incidence rate depends on the rate at which molecules are introduced and the average number of incidences per molecule introduced. The trajectories of the molecules do not depend on their average velocities or types so that the average number of incidences per molecule are not affected by these variables.
- 2) At a fixed gas inlet rate, the number density of molecules in the chamber is proportional to the square root of the molecular weight and inversely proportional to the square root of the absolute temperature of the molecules.



This conclusion is based on the fact that the number of molecules in the chamber is proportional to the time required for them to complete their trajectories and therefore inversely proportional to their velocities. Note that it is the temperature of the molecules that is involved; for any given molecule this temperature is probably almost the same on the average as that of the surface encountered by the molecule immediately prior to observation, and the density of the gas entering a gauge is therefore related to the temperature of only those surfaces "seen" by the opening.

- 3) At a fixed gas admission rate the pressure is directly proportional to the square root of the absolute temperature of the gas molecules because pressure is proportional to the incidence rate and momentum of the gas molecules.

By changing the temperature of the system with a fixed gas inlet rate, it is possible to increase the pressure, decrease the density, and simultaneously maintain a constant molecular incidence rate. It is also possible to change the gas inlet rate as the temperature is changed and so maintain either constant pressure or constant density if desired.

### 2.2.2 Gauges

In order to obtain the desired information, it was necessary to obtain a gauge in which both the tubulation geometry and the gauge temperature could be varied. A series of gauges were designed and are illustrated in Figures 2-5. Five gauges were built.

1. Nude-type permanent reference
2. Nude-type with variable temperature
3. Shielded with orifice opening
4. Shielded with short tube opening
5. Shielded with long tube opening

All but the nude-type are designed to have approximately the same pumping speed of 5 liters per second. The physical dimensions of the tubulations are marked on the sketch. A conventional glass tubulated gauge (Consolidated Vacuum Corporation Model GIC-011) was also included. A photograph of the gauges installed in the vacuum chamber lid is shown in Figure 6.

Note that the "nude" gauges are actually partially enclosed. They can be made to read like true nude gauges with respect to temperature effects, however, by holding the enclosure at the temperature of the impinging gas, as if the enclosing shell were part of the chamber wall. This technique was, in fact, followed for one of the "nude" gauges. Furthermore, the above statement applies not only to the open-ended gauges but to all of the gauges, if held at chamber temperature they behave like nude gauges and sense density.

### 2.2.3 Auxiliary Equipment

Gas was admitted to the system through a section of porous Vycor (Corning No. 7930 glass) 2.5 mm. thick and about 60 cm<sup>2</sup> in area. This material was chosen because the small pore size, about 40 angstroms diameter, is less than the mean free path

of air molecules even at atmospheric pressure. Gas flow through such pores may be expected to be linear with pressure, as in free molecular flow. A conventional capillary type leak is likely to be in a transition zone where the flow is neither molecular nor viscous and its dependence on pressure and gas type is not predictable. The conductance of this leak was found to be about  $4 \times 10^{-4}$  liters/second and according to ion gauge readings the flow was linear with pressure over the operating range. A standard leak showed a departure from linearity under similar conditions, as would be expected. The housing of the leak was water-cooled and equipped with a thermocouple to monitor and control the temperature. The gas pressure applied to the leak was measured as an absolute pressure with a precision barometer and was normally in the range of 5 to 50 mm Hg.

A multichannel switching circuit which had been previously designed for a mass spectrometer was modified to control the readings of the different gauges. The method of control was to connect all the anodes together and to a common D. C. amplifier. Switching was obtained by applying a negative bias to all grids except the one in the tube which is being read. The switching arrangement also applied an auxiliary filament supply voltage to the filaments of the inactive tubes which was individually adjustable so that each tube was maintained at its operating temperature at all times. A null balance emission circuit was used to set emissions at  $100 \pm .5$  microamps, and a precision electrometer was used to measure the ion current.

### 2.3 TEST RESULTS

The response of the gauges to the vacuum chamber conditions was investigated by varying the temperature of the vacuum system walls from cooling water temperature to dry ice temperature. The data shown in Figures 7, 8, and 9, summarize the results of test runs. The gauge readings per unit of gas supply pressure are shown for both Nitrogen and Helium; the scales are chosen in accordance with the published ionization cross-sections of the molecules, so that data points for both gases should coincide. The spans shown for the data points amount to about 1% of the full scale gauge reading, and indicate the estimated errors in reading the instrument scales. The manufacturer of the micro-micro-ammeter used to read the ion current claims only 3% accuracy in the instrument itself and this is estimated to be the major source of instrument error.

Data were taken on four successive days; on the first two days, the four data points correspond to gas supply pressures of approximately 100, 50, 20, and 10 mm. Hg absolute. Points on the last two days were taken at gas supply pressures of approximately 50 mm. Hg. and are intended mainly to serve as checks on the other data. It will be seen that on the second and fourth days, when the vacuum chamber was packed in dry ice, all gauges except No. 6 read the same as at room temperature. Thus, these gauges are shown to be sensitive to incidence rate which was independent of chamber temperature and gas type, rather than pressure or density. Gauge No. 6, which is a nude gauge (with shell at chamber temperature), was found to give a reading inversely proportional to the square root of temperature using nitrogen, as would be expected of a density gauge. The readings obtained with Helium in this gauge do not show a variation of the expected magnitude, however, for reasons not presently known.

The effect of the temperature of the gauge shell was also investigated as a further check on the validity of the analysis. The gauges were cooled with water, cold nitrogen gas, and liquid nitrogen, and both nitrogen and helium were used as test gases. The data obtained are shown in Figures 10, 11, 12 and 13. The solid lines on the graphs are drawn with a slope of minus  $1/2$  corresponding to the inverse square root of temperature effect predicted. It appears that the gauges do respond in the predicted manner. The glass gauge and the nude gauge (open-ended gauge with shell at vacuum chamber temperature) gave readings which were constant and independent of the temperatures of the other gauges.

Further experimental evidence was obtained relative to the statement that when the envelope of a tubulated gauge is maintained at the temperature of the chamber, the reading is the same as that of a nude gauge. Tests were run with the chamber and gauges at cooling water temperature, approximately  $290^{\circ}\text{K}$ , and at dry ice temperature, about  $190^{\circ}\text{K}$ . The gauges were cooled in the latter instance by bleeding in liquid nitrogen at a rate to produce the desired temperature. The temperature difference between inlet and outlet was large in these tests, about  $30$  to  $50^{\circ}\text{K}$ , and the actual effective temperature of the gauges may thus be somewhat different from the average temperature, which was assumed to be the effective temperature of the gauge. Table I shows several readings at each temperature and the ratio of the averages of these readings for each gauge. The ratio of gauge readings is predicted to be the reciprocal of the ratio of the square roots of the respective temperatures if the gauges behave like nude gauges, or about  $1.25$ . With nitrogen as the test gas, the data appear fairly consistent, the glass gauge (not temperature controlled) reading as a molecular flux gauge and the others as nude gauges. With helium, however, the results are not entirely as expected. The readings of the glass gauge as well as the orifice and short tube gauges are as predicted. The long tube gauge and open-ended gauges yielded a smaller change with temperature than was expected. A comparison of the ratios of nitrogen readings to helium readings shows that the readings of all gauges are closer to the expected  $6:1$  ratio at room temperature than at the low temperature. However, there are some unexplained variations in the nitrogen/helium ratios, even at room temperature. Similar results have been reported by Leck (2) where the nitrogen/helium ratios compiled from various sources range from  $4$  to  $7.15$ . Leck also cites two investigations where the variations in nitrogen/helium ratios among apparently identical gauges were  $10$  and  $20\%$  respectively. These discrepancies are too large to be ascribed to experimental error, but the reasons for them are not presently known. It appears that the discrepancies are larger for the inert gases than for the other gases.

Another factor was also observed, but is without explanation. Occasionally, a gauge is found to yield a reading which is not proportional to the emission current. This phenomenon has been observed only in glass gauges and at pressures ranging from  $10^{-4}$  to  $10^{-9}$  torr. The reading of the gauge under these conditions has been found proportional to the  $3/2$  power of the emission (approximately) and the gauge appears to read abnormally low at the usual levels of emission. We have some tentative evidence that this phenomenon is related to the creation of  $\text{CO}$  in the gauge in the presence of oxygen, but there are also other possibilities. This behavior is mentioned because it may be of interest in working with ionization gauges.

Recapitulating briefly, tubulated gauges maintained at constant temperature are shown to respond to molecular flux rate rather than pressure or density. Nude gauges, on the other hand, are shown to respond to density. Tubulated gauges can be made to respond like nude gauges in respect to temperature effects, however, by operating with the gauge shell at the temperature of the vacuum chamber. These statements are well confirmed with nitrogen gas but less well confirmed with helium.

### 3.0 SPACE SIMULATOR GAUGE EXPERIMENTS

The Space Simulator Gauge is designed to indicate molecular incidence rates in space simulation chambers where correction is required for the directional gas flow effects produced by outgassing of a test vehicle in the presence of large cryogenic pumping areas. A gauge directly exposed to the stream of gas desorbed by the vehicle will be subjected to a much higher molecular incidence rate than the surfaces of the vehicle itself, because much of this gas is condensed on the pumping panels at first contact and is never reflected to the vehicle. A gauge can be corrected for this error by incorporating the proper amount of cryogenic pumping in the gauge so that the incident flux of condensible molecules will be reduced by the appropriate fraction before being measured. A study has been undertaken to investigate the characteristics of ion gauges in which pumping is purposely introduced. (See Figures 14 and 15). The intended operating characteristics of these gauges are as follows:

- 1) Response to gases not pumped cryogenically - Responds to molecular incidence rate like conventional tubulated gauges, with a possible temperature effect due to cryogenic surface within the gauge.
- 2) Response to gases cryogenically pumped - Gas enters the gauge at a rate proportional to molecular incidence rate and area of opening. Gas is lost from the gauge either by pumping or escape through the opening, at the same rate; this rate of loss is proportional to the number density and average molecular velocity of the gas and the effective area of condensing surface plus opening. Neglecting any velocity correction due to temperature, the density in the gauge must be lowered in proportion to the ratio of the effective removal area to the gas admission area and the gauge reading is thus lowered by a similar factor. Thus the gauge reads incidence rate multiplied by a constant fraction (the area ratio). By proper design this factor can be made equal to the pumping coefficient of the wall of the space chamber, so that the gauge reads the incidence rate of gas reflected by the chamber wall under the incident gas load.

Although the principle of the Space Simulator Gauge is relatively straightforward, some factors in the design have not been completely evaluated, such as the effect of the location of the entrance hole relative to the grid structure, and effects due to directional gas flow within the gauge.

#### 3.1 PROCEDURE

In order to evaluate the performance of this type of gauge, a modification of the ion gauges studied earlier in this program has been made. The two gauges having open ended shells are used, with a moveable end plate which is cooled by liquid nitrogen and which has a hole for gas admission to the gauge. The end plate can be positioned in front of either gauge and the hole in this plate can be moved with the system under vacuum. The size of the hole was chosen to allow a gas admission area equal to 1/10 of the gas removal area. The gauges are shown in Figures 14 and 15.

Water vapor was used as the test gas in this experiment and the pumping surface was cooled with liquid nitrogen. Water was introduced through a conventional leak at its saturation pressure corresponding to room temperature. Because the tests

were run in the course of about 1 hour, the pressure of the water vapor was not monitored, but the temperature of the room was observed to remain within 1°C during this period, assuring that the vapor pressure of the water was constant during the experiment.

The directionality of flow found in a space simulator was not simulated in this experiment; the flow was essentially random. This course was followed because the directionality of flow is not essential to the operation of the gauge. The gauge is intended merely to register only 10% condensible gas incident on it, as if this gas were incident upon a space simulator wall where 90% was pumped and 10% reflected back to the vehicle under test.

### 3.2 RESULTS

The results obtained with water vapor are shown in Figure 16. The pumping surface reduced the gauge reading by a factor of 10.3 to 9.8, versus a calculated value of 10.2, based on the actual dimensions of the gauge. In addition, the gauge reading was somewhat sensitive to the position of the hole relative to the gauge element. In this test a 23/32" hole was used with a 2 1/2" ID gauge shell. The reading was highest with the hole in the center and decreased 15 to 20% as the hole was removed over to the point of tangency with the gauge shell. In the figure shown the further decrease in the readings with additional shifting of the hole results from the hole being only partially exposed to the gauge. The rapid rise at the extremes of the traverse indicates that the end of the gauge is no longer fully covered by the cold plate.

The change in reading as the hole is shifted evidently reflects a nonuniformity of distribution due to the pumping action of the gauge. It is suggested that with the hole in the center of the gauge and with random gas incidence on the hole, the incoming molecules are distributed fairly uniformly over the inside of the gauge. These molecules bounce around an average of six times before being condensed on the cold plate or escaping from the gauge, thus contributing a certain gas density within the gauge. When the hole is moved close to the side wall of the gauge, the molecular distribution is no longer uniform, more molecules hitting the side wall of the gauge near the orifice than elsewhere. These molecules have a somewhat higher probability of escaping or being pumped than those farther from the cold plate, and the average density of the gas in the gauge is therefore lower.

The behavior of the gauge with gases not pumped cryogenically was determined in the earlier part of the program when the temperature of the vacuum chamber was changed. It was found that there was no measureable change in readings when the chamber was chilled with dry ice, as compared to being at room temperature. The cold plate in front of the gauge is topologically similar to the cold chamber. The temperature of the cold plate is quite a bit lower than that of the cold chamber, however, so that a small effect may be present. The maximum magnitude of this effect can be estimated as follows:

The number of molecules incident on the cold plate in a given time interval is about 15% of the total incident on the surfaces of the gauge (on the basis of areas). These 15%, it will be assumed, are chilled to about 100°K, from their

normal 300°K and their velocities are thus reduced. Consequently the time of passage through the ionizing zone is increased by  $\sqrt{3}$ . The relative frequency with which ions are produced is  $.15/\sqrt{3}$  or .26 for the cold molecules and  $(1.00-.15)$  or .85 for the remainder. The net effect is then an ion current about 1.11 times the normal ion current of the gauge. For the cold chamber at dry ice temperature, the effect should be a factor of about 1.03 times the normal reading.

#### 4.0 CONCLUSIONS

1. The response of nude ionization gauges is proportional to the density of the gas in the vacuum chamber and depends on the gas type.
2. The response of tubulated ionization gauges in which the shell enclosing the sensing element is held at constant temperature is proportional to the molecular flux incident on the mouth of the gauge tubulation.
3. The response of tubulated ionization gauges in which the shell enclosing the sensing element is maintained at the temperature of the vacuum system is similar to the response of nude gauges, that is, proportional to the density of the gas in the vacuum chamber.
4. The degree of enclosure required to make a gauge effectively tubulated is not great. Gauges enclosed with cylindrical shells 2 1/2" diameter x 3" long, open on one end, behaved like tubulated gauges.
5. The space simulator gauge principle, reducing the sensitivity to cryogenically pumped gases by a specified factor to simulate reflection of these gases from a partially pumping wall can be accomplished. More specifically, the reduction in response by a specified factor has been demonstrated; that this simulates the wall pumping effect has not been demonstrated.



REFERENCES

1. Redhead, P. A., "Errors in the Measurement of Pressure with Ionization Gauges", Vacuum Tech. Trans. Proc. 7th Nat. Symp., Pergamon Press, 1960, p. 108.
2. Leck, J. H., Pressure Measurements in Vacuum Systems, Institute of Physics, (Chapman-Hall Ltd.), London, 1957, p. 69.

TABLE 1  
GAUGE RESPONSE WITH GAUGE SHELLS AT VACUUM CHAMBER TEMPERATURE  
FIGURES ARE AMP.  $\times 10^9$  PER TORR GAS SUPPLY PRESSURE  
AT .1 MA. EMISSION  
NITROGEN GAS

| <u>Gauge Type</u>                 | <u>Response at 290°K</u> | <u>Response at 190°K</u> | <u>Ratio</u> |
|-----------------------------------|--------------------------|--------------------------|--------------|
| Glass<br>(Ambient<br>Temperature) | 16.9                     | 16.7                     | .99          |
|                                   | 17                       | 16.7                     |              |
|                                   | <u>16.9</u>              | <u>16.0</u>              |              |
|                                   | 16.9                     | 16.7                     |              |
| Open End<br>(No.2)                | 19.1                     | 23.4                     | 1.23         |
|                                   | 19.1                     | 23.7                     |              |
|                                   | <u>19.4</u>              | <u>23.7</u>              |              |
|                                   | 19.2                     | 23.6                     |              |
| Open End<br>(No. 6)               | 22.7                     | 28.9                     | 1.28         |
|                                   | 22.6                     | 28.8                     |              |
|                                   | <u>22.3</u>              | <u>28.8</u>              |              |
|                                   | 22.5                     | 28.8                     |              |
| Orifice                           | 21.3                     | 26.6                     | 1.27         |
|                                   | 21.4                     | 27.0                     |              |
|                                   | <u>20.7</u>              | <u>26.9</u>              |              |
|                                   | 21.1                     | 26.8                     |              |
| Long Tube                         | 16.9                     | 21.6                     | 1.26         |
|                                   | 16.5                     | <u>22.1</u>              |              |
|                                   | 18.4                     | 21.8                     |              |
|                                   | <u>17.5</u>              |                          |              |
|                                   | 17.3                     |                          |              |
| Short Tube                        | 23.1                     | 29.5                     | 1.28         |
|                                   | 23.5                     | 30.2                     |              |
|                                   | <u>22.9</u>              | <u>29.7</u>              |              |
|                                   | 23.2                     | 29.8                     |              |

TABLE 1 (Concluded)  
 AMP. PER MM. GAS SUPPLY PRESSURE  $\times 10^9$   
 AT .1 MA. EMISSION  
 HELIUM GAS

| <u>Gauge Type</u>              | <u>Response at 290°K</u>    | <u>Response at 190°K</u>            | <u>Ratio</u> |
|--------------------------------|-----------------------------|-------------------------------------|--------------|
| Glass<br>(Ambient Temperature) | 2.54<br><u>2.62</u><br>2.58 | 2.56<br>2.50<br><u>2.50</u><br>2.52 | .98          |
| Open End<br>(No.2)             | 3.31<br><u>3.20</u><br>3.25 | 3.62<br><u>3.52</u><br>3.55         | 1.09         |
| Open End<br>(No.6)             | 3.81<br><u>3.92</u><br>3.86 | 4.07<br><u>4.03</u><br>4.05         | 1.05         |
| Orifice                        | 3.03<br><u>3.12</u><br>3.07 | 3.85<br>3.77<br><u>3.73</u><br>3.75 | 1.22         |
| Long Tube                      | 3.07<br><u>2.96</u><br>3.01 | 3.52<br><u>3.42</u><br>3.47         | 1.15         |
| Short Tube                     | 3.52<br><u>3.42</u><br>3.47 | 4.28<br><u>4.23</u><br>4.26         | 1.23         |

**TABLE 2**  
**EFFECT OF CHAMBER TEMPERATURE ON GAUGE RESPONSE**

READINGS IN AMP  $\times 10^9$  at  $100 \pm .05$  MICROAMP EMISSION

$P_s$  = Gas Supply Pressure - torr

$R$  = Observed Reading

$R_o$  = Background Reading

$R_p$  = Back Pressure Behind Orifice

$R_n$  = Net Reading =  $(R - R_o) - (R_p - R_{p_o})$

err =  $\pm$  Estimated Reading Error

RUN NO. 1 (11/27) GAUGE TEMPERATURE  $18^\circ\text{C}$

CHAMBER TEMPERATURE  $18^\circ\text{C}$  - NITROGEN GAS

| $P_s$  | err | R    | err | $R - R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|--|-----|------|-----|-----------|-----|-------|-----|-------------------|-----|
| Gauge No. 1 Commercial Glass Tubulated Gauge (CVC) |     |      |     |           |     |       |     |                   |     |
| 96.2   | .05 | 1800 | 30  | 1800      | 30  | 1580  | 40  | 16.4              | .4  |
| 51.4   | .05 | 930  | 10  | 930       | 10  | 810   | 20  | 15.7              | .4  |
| 21.0   | .05 | 380  | 10  | 380       | 10  | 330   | 12  | 15.7              | .6  |
| 10.7   | .05 | 187  | 3   | 186       | 3   | 161   | 5   | 15.1              | .5  |
| Background   |     |      |     |           |     |       |     |                   |     |
| 0  | .05 | 1.65 | .05 |           |     |       |     |                   |     |
| Gauge No. 2 Open End                               |     |      |     |           |     |       |     |                   |     |
| 96.2   | .05 | 2080 | 30  | 2080      | 30  | 1860  | 40  | 19.3              | .4  |
| 51.4   | .05 | 950  | 10  | 950       | 10  | 830   | 20  | 16.1              | .4  |
| 21.0   | .05 | 420  | 10  | 420       | 10  | 370   | 12  | 17.6              | .6  |
| 10.7   | .05 | 208  | 3   | 206       | 3   | 181   | 5   | 16.9              | .5  |
| Background   |     |      |     |           |     |       |     |                   |     |
| 0  | .05 | 2.60 | .05 |           |     |       |     |                   |     |

TABLE 2 (Continued)

RUN NO. 1 (Concluded)

| $P_s$   | err | R    | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|---|-----|------|-----|---------|-----|-------|-----|-------------------|-----|
| Gauge No. 3 5 l/Sec. Orifice                  |     |      |     |         |     |       |     |                   |     |
| 96.2  | .05 | 2070 | 30  | 2070    | 30  | 1850  | 40  | 19.2              | .4  |
| 51.4  | .05 | 1100 | 30  | 1100    | 30  | 980   | 40  | 19.1              | .8  |
| 21.0  | .05 | 450  | 10  | 450     | 10  | 400   | 12  | 19.0              | .6  |
| 10.7  | .05 | 217  | 3   | 215     | 3   | 191   | 5   | 17.9              | .5  |
| Background                                    |     |      |     |         |     |       |     |                   |     |
| 0   | .05 | 2.00 | .05 |         |     |       |     |                   |     |
| Gauge No. 4 Long Tube                         |     |      |     |         |     |       |     |                   |     |
| 96.2  | .05 | 1600 | 30  | 1600    | 30  | 1480  | 40  | 15.4              | .4  |
| 51.4  | .05 | 850  | 10  | 850     | 10  | 730   | 20  | 14.2              | .4  |
| 21.0  | .05 | 370  | 10  | 367     | 10  | 317   | 12  | 15.2              | .6  |
| 10.7  | .05 | 195  | 3   | 192     | 3   | 166   | 5   | 15.5              | .5  |
| Background                                    |     |      |     |         |     |       |     |                   |     |
| 0   | .05 | 2.95 | .05 |         |     |       |     |                   |     |
| Gauge No. 5 Short Tube                        |     |      |     |         |     |       |     |                   |     |
| 96.2  | .05 | 2170 | 30  | 2170    | 30  | 1950  | 40  | 20.3              | .4  |
| 51.4  | .05 | 1180 | 30  | 1180    | 30  | 1060  | 40  | 20.6              | .4  |
| 21.0  | .05 | 490  | 10  | 487     | 10  | 437   | 12  | 20.9              | .6  |
| 10.7  | .05 | 240  | 3   | 237     | 3   | 211   | 5   | 19.6              | .5  |
| Background                                    |     |      |     |         |     |       |     |                   |     |
| 0   | .05 | 3.10 | .05 |         |     |       |     |                   |     |
| Gauge No. 6 Open End                          |     |      |     |         |     |       |     |                   |     |
| 96.2  | .05 | 2150 | 30  | 2150    | 30  | 1930  | 40  | 20.1              | .4  |
| 51.4  | .05 | 1180 | 30  | 1180    | 30  | 1060  | 40  | 20.6              | .8  |
| 21.0  | .05 | 480  | 10  | 480     | 10  | 430   | 12  | 20.5              | .6  |
| 10.7  | .05 | 245  | 3   | 242     | 3   | 216   | 5   | 20.2              | .5  |
| Background                                    |     |      |     |         |     |       |     |                   |     |
| 0   | .05 | 2.95 | .05 |         |     |       |     |                   |     |
| Gauge No. 7 Back-Pressure Behind Pump Orifice |     |      |     |         |     |       |     |                   |     |
| 96.2  | .05 | 222  | 10  | 220     | 10  |       |     | 2.29              | .1  |
| 51.4  | .05 | 122  | 10  | 120     | 10  |       |     | 2.43              | .2  |
| 21.0  | .05 | 54.4 | 2   | 52.0    | 2   |       |     | 2.48              | .1  |
| 10.7  | .05 | 28.4 | 2   | 26.0    | 2   |       |     | 2.42              | .2  |
| Background                                    |     |      |     |         |     |       |     |                   |     |
| 0   | .05 | 2.4  |     |         |     |       |     |                   |     |

TABLE 2 (Continued)  
 RUN NO. 2 (11/27) GAUGE TEMPERATURE 18°C  
 CHAMBER TEMPERATURE 18°C - HELIUM GAS

| $P_s$  | err | R    | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|--|-----|------|-----|---------|-----|-------|-----|-------------------|-----|
| Gauge No. 1 Commercial Glass Tubulated Gauge (CVC) |     |      |     |         |     |       |     |                   |     |
| 97.7   | .05 | 192  | 3   | 190     | 3   | 155   | 5   | 1.59              | .05 |
| 49.5   | .05 | 137  | 3   | 135     | 3   | 117   | 4   | 2.86              | .08 |
| 19.9   | .05 | 53   | 1   | 51.3    | 1   | 44    | 1.3 | 2.21              | .07 |
| 10.0   | .05 | 27.3 | 3   | 25.6    | .3  | 22.2  | .5  | 2.21              | .05 |
| Background   |     |      |     |         |     |       |     |                   |     |
| 0  | .05 | 1.70 | .03 |         |     |       |     |                   |     |
| Gauge No. 2 Open End                               |     |      |     |         |     |       |     |                   |     |
| 97.7   | .05 | 330  | 10  | 328     | 10  | 293   | 11  | 3.00              | .11 |
| 49.5   | .05 | 170  | 3   | 168     | 3   | 150   | 4   | 3.03              | .08 |
| 19.9   | .05 | 69   | 1   | 67      | 1   | 60    | 1.3 | 3.02              | .07 |
| 10.0   | .05 | 36   | 1   | 33.8    | 1   | 30    | 1.2 | 3.00              | .12 |
| Background   |     |      |     |         |     |       |     |                   |     |
| 0  | .05 | 2.20 | .03 |         |     |       |     |                   |     |
| Gauge No. 3 Orifice                                |     |      |     |         |     |       |     |                   |     |
| 97.7   | .05 | 355  | 10  | 353     | 10  | 318   | 11  | 3.25              | .11 |
| 49.5   | .05 | 178  | 3   | 176     | 3   | 158   | 4   | 3.20              | .08 |
| 19.9   | .05 | 72   | 1   | 70      | 1   | 63    | 1.3 | 3.16              | .06 |
| 10.0   | .05 | 40   | 1   | 38      | 1   | 35    | 1.2 | 3.50              | .12 |
| Background   |     |      |     |         |     |       |     |                   |     |
| 0  | .05 | 1.97 | .03 |         |     |       |     |                   |     |
| Gauge No. 4 Long Tube                              |     |      |     |         |     |       |     |                   |     |
| 97.7   | .05 | 287  | 10  | 285     | 10  | 250   | 11  | 2.56              | .11 |
| 49.5   | .05 | 155  | 3   | 153     | 10  | 135   | 4   | 2.73              | .08 |
| 19.9   | .05 | 60   | 1   | 58      | 1   | 51    | 1.3 | 2.56              | .07 |
| 10.0   | .05 | 30   | 1   | 28      | 1   | 24    | 1.2 | 2.40              | .12 |
| Background   |     |      |     |         |     |       |     |                   |     |
| 0  | .05 | 2.25 | .03 |         |     |       |     |                   |     |
| Gauge No. 5 Short Tube                             |     |      |     |         |     |       |     |                   |     |
| 97.7   | .05 | 360  | 10  | 358     | 10  | 323   | 11  | 3.30              | .11 |
| 49.5   | .05 | 180  | 3   | 178     | 10  | 160   | 4   | 3.24              | .08 |
| 19.9   | .05 | 72   | 1   | 70      | 1   | 63    | 1.3 | 3.16              | .07 |
| 10.0   | .05 | 37.5 | 1   | 35.2    | 1   | 32.0  | 1.2 | 3.20              | .12 |
| Background   |     |      |     |         |     |       |     |                   |     |
| 0  | .05 | 2.25 | .03 |         |     |       |     |                   |     |

TABLE 2 (Continued)

RUN NO. 2 (Concluded)

| $P_s$   | err | R    | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|---|-----|------|-----|---------|-----|-------|-----|-------------------|-----|
| <hr/>   |     |      |     |         |     |       |     |                   |     |
| Gauge No. 6 Open End                          |     |      |     |         |     |       |     |                   |     |
| 97.7  | .05 | 365  | 10  | 362     | 10  | 328   | 11  | 3.36              | .11 |
| 49.5  | .05 | 183  | 3   | 180     | 3   | 163   | 4   | 3.30              | .08 |
| 19.9  | .05 | 74   | 1   | 71.4    | 1   | 65    | 1.3 | 3.27              | .07 |
| 10.0  | .05 | 39   | 1   | 36.4    | 1   | 33    | 1.2 | 3.30              | .12 |
| Background                                    |     |      |     |         |     |       |     |                   |     |
| 0   | .05 | 2.60 | .03 |         |     |       |     |                   |     |
| Gauge No. 7 Back Pressure Behind Pump Orifice |     |      |     |         |     |       |     |                   |     |
| 97.7  | .05 | 37   | 1   | 35      | 1   |       |     | .358              |     |
| 49.5  | .05 | 20   | 1   | 18      | 1   |       |     | .364              |     |
| 19.9  | .05 | 8.8  | .2  | 7.2     | .3  |       |     | .362              |     |
| 10.0  | .05 | 5.0  | .1  | 3.4     | .2  |       |     | .340              |     |
| 0   | .05 | 1.6  | .1  |         |     |       |     |                   |     |

TABLE 2 (Continued)

| RUN NO. 3 (11/28) GAUGE TEMPERATURE AS NOTED                              |      |     |         |     |       |     |                   |     |
|---|------|-----|---------|-----|-------|-----|-------------------|-----|
| CHAMBER TEMPERATURE -90°C - NITROGEN GAS                                  |      |     |         |     |       |     |                   |     |
| $P_s$   | R    | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
| Gauge No. 1 Commercial Glass Tubulated Gauge (CVC)<br>Ambient Temperature |      |     |         |     |       |     |                   |     |
| 0   | 1.5  | .03 |         |     |       |     |                   |     |
| 91.5  | 1620 | 30  | 1620    | 30  | 1420  | 40  | 15.5              | .4  |
| 44.7  | 770  | 10  | 770     | 10  | 660   | 20  | 14.8              | .4  |
| 19.8  | 340  | 3   | 340     | 3   | 290   | 4   | 14.6              | .2  |
| 9.8   | 167  | 3   | 165     | 3   | 142   | 4   | 14.5              | .4  |
| Gauge No. 2 Open End 20°C   |      |     |         |     |       |     |                   |     |
| 0   | 1.6  | .03 |         |     |       |     |                   |     |
| 91.5  | 1820 | 30  | 1820    | 30  | 1620  | 40  | 17.7              | .4  |
| 44.7  | 920  | 10  | 920     | 10  | 810   | 20  | 17.8              | .4  |
| 19.8  | 390  | 10  | 388     | 10  | 340   | 11  | 17.2              | .5  |
| 9.8   | 197  | 3   | 195     | 3   | 172   | 4   | 17.6              | .4  |
| Gauge No. 3 Orifice 20°C  |      |     |         |     |       |     |                   |     |
| 0   | 2.1  | .03 |         |     |       |     |                   |     |
| 91.5  | 1720 | 30  | 1720    | 30  | 1520  | 40  | 16.7              | .4  |
| 44.7  | 860  | 10  | 860     | 10  | 750   | 20  | 16.8              | .4  |
| 19.8  | 375  | 10  | 373     | 10  | 325   | 11  | 16.4              | .5  |
| 9.8   | 180  | 3   | 178     | 3   | 155   | 4   | 15.8              | .4  |
| Gauge No. 4 Long Tube 20°C  |      |     |         |     |       |     |                   |     |
| 0   | 2.5  | .03 |         |     |       |     |                   |     |
| 91.5  | 1520 | 30  | 1520    | 30  | 1320  | 40  | 14.4              | .4  |
| 44.7  | 730  | 10  | 730     | 10  | 620   | 20  | 13.9              | .4  |
| 19.8  | 355  | 10  | 353     | 10  | 305   | 11  | 15.8              | .5  |
| 9.8   | 180  | 3   | 178     | 3   | 155   | 4   | 15.8              | .4  |
| Gauge No. 5 Short Tube 20°C   |      |     |         |     |       |     |                   |     |
| 0   | 2.3  | .03 |         |     |       |     |                   |     |
| 91.5  | 2000 | 30  | 2000    | 30  | 1800  | 40  | 19.7              | .4  |
| 44.7  | 975  | 10  | 975     | 10  | 865   | 20  | 19.3              | .4  |
| 19.8  | 445  | 10  | 443     | 10  | 395   | 11  | 19.9              | .5  |
| 9.8   | 220  | 3   | 218     | 3   | 195   | 4   | 19.9              | .4  |
| Gauge No. 6 Open End -90°C  |      |     |         |     |       |     |                   |     |
| 0   | 2.2  | .03 |         |     |       |     |                   |     |
| 91.5  | 2800 | 30  | 2800    | 30  | 2600  | 40  | 28.4              | .4  |
| 44.7  | 1330 | 30  | 1330    | 30  | 1220  | 40  | 27.3              | .8  |
| 19.8  | 560  | 10  | 558     | 10  | 510   | 11  | 25.7              | .5  |
| 9.8   | 280  | 3   | 278     | 3   | 255   | 4   | 26.0              | .4  |



TABLE 2 (Continued)  
 RUN NO. 3 (Concluded)

| $P_s$  | R   | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|--|-----|-----|---------|-----|-------|-----|-------------------|-----|
| Gauge No. 7 Back pressure, ambient temperature |     |     |         |     |       |     |                   |     |
| 0  | 1.4 | .1  |         |     |       |     |                   |     |
| 91.5   | 200 | 10  | 199     | 10  |       |     | 2.18              | .1  |
| 44.7   | 110 | 10  | 109     | 10  |       |     | 2.46              | .2  |
| 19.8   | 50  | 1   | 49.6    | 1   |       |     | 2.47              | .05 |
| 9.8  | 25  | 1   | 23.6    | 1   |       |     |                   |     |

TABLE 2 (Continued)

RUN NO. 4 (11/28) GAUGE TEMPERATURE AS NOTED  
CHAMBER TEMPERATURE -90°C - HELIUM GAS

| $P_s$   | R    | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|---|------|-----|---------|-----|-------|-----|-------------------|-----|
| Gauge No. 1 Glass Gauge - Ambient Temperature |      |     |         |     |       |     |                   |     |
| 0   | 1.4  | .03 |         |     |       |     |                   |     |
| 98.1  | 273  | 3   | 272     | 3   | 236   | 4   | 2.41              | .04 |
| 48.7  | 130  | 3   | 129     | 3   | 111   | 4   | 2.28              | .08 |
| 20.9  | 55   | 1   | 54      | 1   | 46    | 1.2 | 2.20              | .06 |
| 10.9  | 29   | .3  | 27.6    | .3  | 23.7  | .5  | 2.17              | .05 |
| Gauge No. 2 Open End, 18°C                    |      |     |         |     |       |     |                   |     |
| 0   | 1.5  | .03 |         |     |       |     |                   |     |
| 98.1  | 325  | 10  | 324     | 10  | 288   | 11  | 2.94              | .11 |
| 48.7  | 160  | 3   | 159     | 3   | 141   | 4   | 2.90              | .08 |
| 20.9  | 70   | 1   | 68.5    | 1   | 61    | 1.2 | 2.92              | .06 |
| 10.9  | 36   | 1   | 34.5    | 1   | 30.6  | 1.2 | 2.81              | .12 |
| Gauge No. 3 Orifice, 18°C                     |      |     |         |     |       |     |                   |     |
| 0   | 1.6  | .03 |         |     |       |     |                   |     |
| 98.1  | 270  | 3   | 268     | 3   | 233   | 4   | 2.38              | .04 |
| 49.5  | 133  | 3   | 131     | 3   | 114   | 4   | 2.30              | .08 |
| 20.9  | 55   | 1   | 53.4    | 1   | 46    | 1.2 | 2.20              | .06 |
| 10.9  | 32   | 1   | 30.4    | 1   | 27.5  | 1.2 | 2.52              | .12 |
| Gauge No. 4 Long Tube, 18°C                   |      |     |         |     |       |     |                   |     |
| 0   | 1.88 | .03 |         |     |       |     |                   |     |
| 98.1  | 285  | 3   | 283     | 3   | 248   | 4   | 2.53              | .04 |
| 48.7  | 152  | 3   | 150     | 3   | 133   | 4   | 2.73              | .08 |
| 20.9  | 73   | 1   | 71      | 1   | 64    | 1.2 | 3.06              | .06 |
| 10.9  | 42   | 1   | 40      | 1   | 36    | 1.2 | 3.38              | .12 |
| Gauge No. 5 Short Tube, 18°C                  |      |     |         |     |       |     |                   |     |
| 0   | 1.83 | .03 |         |     |       |     |                   |     |
| 98.1  | 355  | 10  | 353     | 10  | 318   | 11  | 3.24              | .11 |
| 48.7  | 183  | 3   | 181     | 3   | 164   | 4   | 3.37              | .08 |
| 20.9  | 75   | 1   | 73      | 1   | 66    | 1.2 | 3.15              | .06 |
| 10.9  | 40   | 1   | 38.2    | 1   | 34    | 1.2 | 3.12              | .12 |

TABLE 2 (Continued)  
 RUN NO. 4 (Concluded)

| $P_s$   | R   | err | $R-R_o$ | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|---|-----|-----|---------|-----|-------|-----|-------------------|-----|
| Gauge No. 6 Open End, $-90^{\circ}\text{C}$     |     |     |         |     |       |     |                   |     |
| 0   | 2.1 | .03 |         |     |       |     |                   |     |
| 98.1  | 420 | 10  | 418     | 10  | 383   | 11  | 3.90              | .11 |
| 48.7  | 210 | 3   | 208     | 3   | 191   | 4   | 3.92              | .08 |
| 20.9  | 86  | 1   | 84      | 1   | 77    | 1.2 | 3.68              | .06 |
| 10.9  | 46  | 1   | 44      | 1   | 40    | 1.2 | 3.67              | .05 |
| Gauge No. 7 Back Pressure - Ambient Temperature |     |     |         |     |       |     |                   |     |
| 0   | 1.5 | .1  |         |     |       |     |                   |     |
| 98.1  | 37  | 1   | 35.5    | 1.1 |       |     | .362              | .01 |
| 48.7  | 19  | 1   | 17.5    | 1.1 |       |     | .369              | .02 |
| 20.9  | 9   | .1  | 7.5     | .2  |       |     | .358              | .01 |
| 10.9  | 5.4 | .1  | 3.9     | .2  |       |     | .358              | .02 |

TABLE 2 (Continued)

RUN NO. 5 (11/29) GAUGE TEMPERATURE 18°C  
 CHAMBER TEMPERATURE 18°C - NITROGEN GAS  
 $P_s = 49.0$  TORR

| Gauge | R    | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|-------|------|-----|-------|-----|-------------------|-----|
| 1     | 850  | 10  | 750   | 20  | 15.3              | .4  |
| 2     | 960  | 10  | 860   | 20  | 17.6              | .4  |
| 3     | 1080 | 30  | 980   | 40  | 20.0              | .8  |
| 4     | 810  | 10  | 710   | 20  | 14.5              | .4  |
| 5     | 1130 | 30  | 1030  | 40  | 21.0              | .8  |
| 6     | 1110 | 30  | 1010  | 40  | 20.6              | .8  |

RUN NO. 6 (11/29) GAUGE TEMPERATURE 18°C  
 CHAMBER TEMPERATURE 18°C - HELIUM GAS  
 $P_s = 50.0$  TORR

| Gauge | R   | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|-------|-----|-----|-------|-----|-------------------|-----|
| 1     | 133 | 3   | 113   | 4   | 2.26              | .08 |
| 2     | 162 | 3   | 142   | 4   | 2.84              | .08 |
| 3     | 158 | 3   | 138   | 4   | 2.76              | .08 |
| 4     | 150 | 3   | 130   | 4   | 2.60              | .08 |
| 5     | 173 | 3   | 153   | 4   | 3.06              | .08 |
| 6     | 198 | 3   | 178   | 4   | 3.56              | .08 |
| 7     | 20  | 1   |       |     |                   |     |

RUN NO. 7 (11/30) GAUGE TEMPERATURE AS NOTED  
 CHAMBER TEMPERATURE -90°C - NITROGEN GAS  
 $P_s = 49.2$  TORR

| Gauge | Temp.<br>°C | R    | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|-------|-------------|------|-----|-------|-----|-------------------|-----|
| 1     | Amb.        | 830  | 10  | 710   | 20  | 14.4              | .4  |
| 2     | 18          | 940  | 10  | 820   | 20  | 16.7              | .4  |
| 3     | 18          | 1050 | 30  | 930   | 40  | 18.9              | .4  |
| 4     | 18          | 830  | 10  | 710   | 20  | 14.4              | .4  |
| 5     | 18          | 1100 | 30  | 980   | 40  | 19.9              | .4  |
| 6     | -90         | 1400 | 30  | 1280  | 40  | 26.0              | .4  |
| 7     | Amb.        | 120  | 10  |       |     |                   |     |

TABLE 2 (Concluded)

RUN NO. 8 (11/30) GAUGE TEMPERATURE AS NOTED

CHAMBER TEMPERATURE  $-90^{\circ}\text{C}$  - HELIUM GAS $P_s = 51.0$  TORR

| Gauge | Temp.<br>$^{\circ}\text{C}$ | R   | err | $R_n$ | err | $\frac{R_n}{P_s}$ | err |
|-------|-----------------------------|-----|-----|-------|-----|-------------------|-----|
| 1     | Amb.                        | 135 | 3   | 115   | 4   | 2.25              | .08 |
| 2     | 18                          | 162 | 3   | 142   | 4   | 2.78              | .08 |
| 3     | 18                          | 160 | 3   | 140   | 4   | 2.74              | .08 |
| 4     | 18                          | 151 | 3   | 131   | 4   | 2.57              | .08 |
| 5     | 18                          | 180 | 3   | 160   | 4   | 3.14              | .08 |
| 6     | -90                         | 210 | 3   | 190   | 4   | 3.72              | .08 |
| 7     | Amb.                        | 20  | 1   |       |     |                   |     |

**TABLE 3**  
**EFFECT OF GAUGE TEMPERATURE ON GAUGE RESPONSE**

READINGS IN AMP  $\times 10^9$  at 100 MICROAMP EMISSION  
 CHAMBER TEMPERATURE = 18°C

| Gauge                                | Inlet<br>Temp. °K | Outlet<br>Temp. °K | R   | $\frac{R}{P_s}$ |
|--------------------------------------|-------------------|--------------------|-----|-----------------|
| Nitrogen Gas $P_s = 18.8$ Torr       |                   |                    |     |                 |
| 1. Glass                             | Amb.              | -                  | 320 |                 |
| 2. Open End                          | 193               | 210                | 400 | 21.3            |
| 3. Orifice                           | 193               | 222                | 480 | 25.5            |
| 4. Long Tube                         | 193               | 236                | 360 | 19.2            |
| 5. Short Tube                        | 207               | 241                | 490 | 26.0            |
| 6. Open End                          | 289               | 289                | 420 |                 |
| 7. Back Pressure                     | Amb.              | -                  | 45  |                 |
| 1. Glass                             | Amb.              |                    | 320 |                 |
| 2. Open End                          | 84                | 95                 | 610 | 32.4            |
| 3. Orifice                           | 84                | 89                 | 760 | 40.4            |
| 4. Long Tube                         | 84                | 89                 | 550 | 29.2            |
| 5. Short Tube                        | 115               | 119                | 720 | 38.3            |
| 6. Open End                          | 289               | 289                | 420 |                 |
| 7. Back Pressure                     | Amb.              |                    | 45  |                 |
| 1. Glass                             | Amb.              |                    | 320 |                 |
| 2. Open End                          | 289               | 289                | 365 | 19.4            |
| 3. Orifice                           | 289               | 289                | 390 | 20.7            |
| 4. Long Tube                         | 289               | 289                | 330 | 17.6            |
| 5. Short Tube                        | 289               | 289                | 430 | 22.9            |
| 6. Open End                          | 289               | 289                | 420 |                 |
| 7. Back Pressure                     | Amb.              |                    | 45  |                 |
| Helium Gas $P_s = 17.5$ Torr Approx. |                   |                    |     |                 |
| 1. Glass                             | Amb.              |                    | 48  | 2.70            |
| 2. Open End                          | 289               | 289                | 61  | 3.43            |
| 3. Orifice                           | 289               | 289                | 56  | 3.14            |
| 4. Long Tube                         | 289               | 289                | 56  | 3.18            |
| 5. Short Tube                        | 289               | 289                | 64  | 3.63            |
| 6. Open End                          | 289               | 289                | 69  | 3.41            |
| 7. Back Pressure                     | Amb.              |                    | 8.7 |                 |

TABLE 3 (Concluded)

| Gauge            | Inlet<br>Temp, °K | Outlet<br>Temp, °K | R   | $\frac{R}{P_s}$ |
|------------------|-------------------|--------------------|-----|-----------------|
| 1. Glass         | Amb.              |                    | 49  | 2.88            |
| 2. Open End      | 110               | 115                | 96  | 5.64            |
| 3. Orifice       | 105               | 115                | 100 | 5.88            |
| 4. Long Tube     | 105               | 110                | 85  | 5.00            |
| 5. Short Tube    | 110               | 115                | 115 | 6.77            |
| 6. Open End      | 289               | 289                | -   |                 |
| 7. Back Pressure | Amb.              |                    | 8.5 |                 |
| 1. Glass         | Amb.              |                    | 46  | 2.64            |
| 2. Open End      | 275               | 280                | 60  | 3.45            |
| 3. Orifice       | 255               | 270                | 57  | 3.28            |
| 4. Long Tube     | 283               | 291                | 53  | 3.04            |
| 5. Short Tube    | 293               | 305                | 60  | 3.45            |
| 6. Open End      | 289               | 289                | 78  | 4.48            |
| 7. Back Pressure | Amb.              |                    | 8.5 |                 |



Fig. 1 Experimental Apparatus



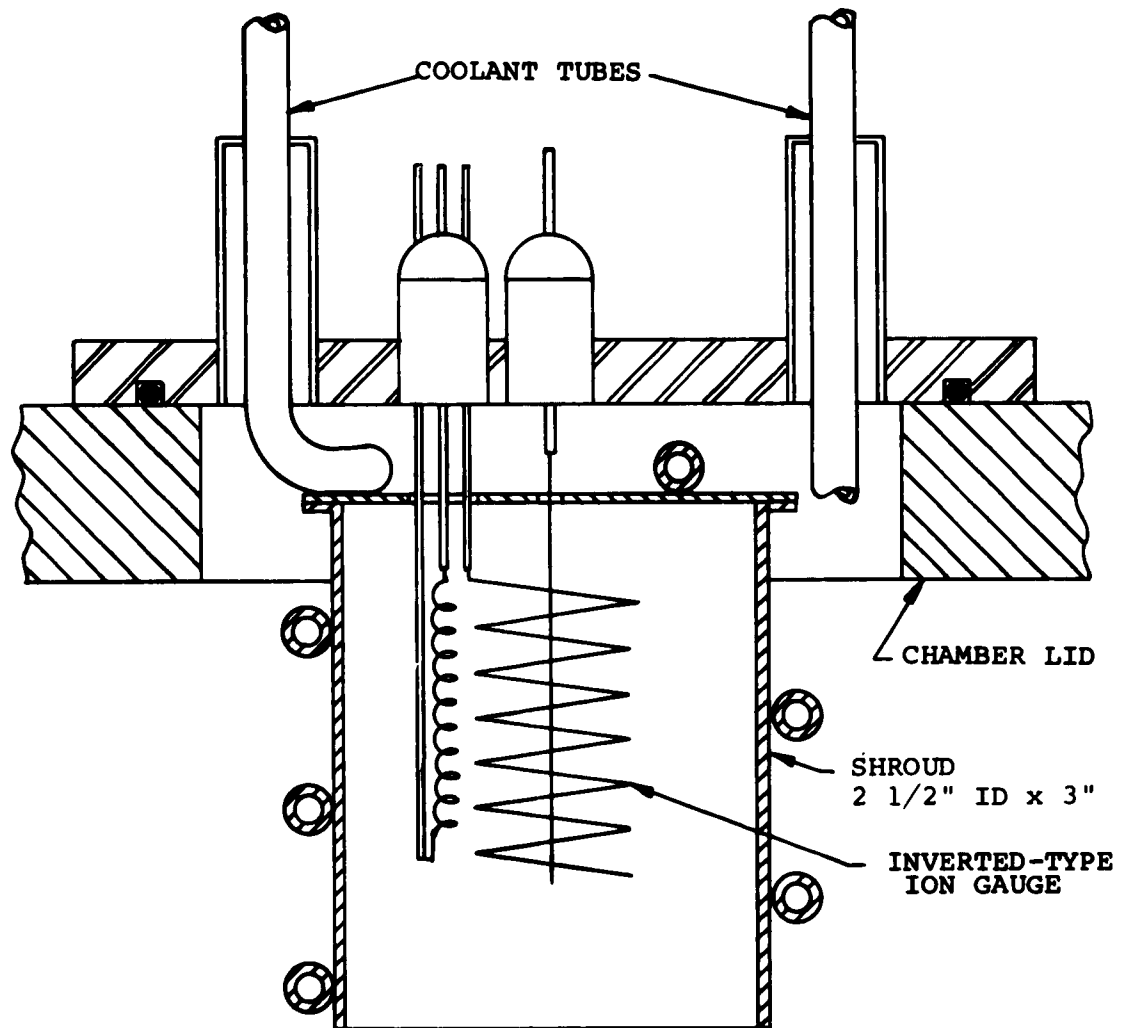


Fig. 2 Experimental Nude Ion Gauge

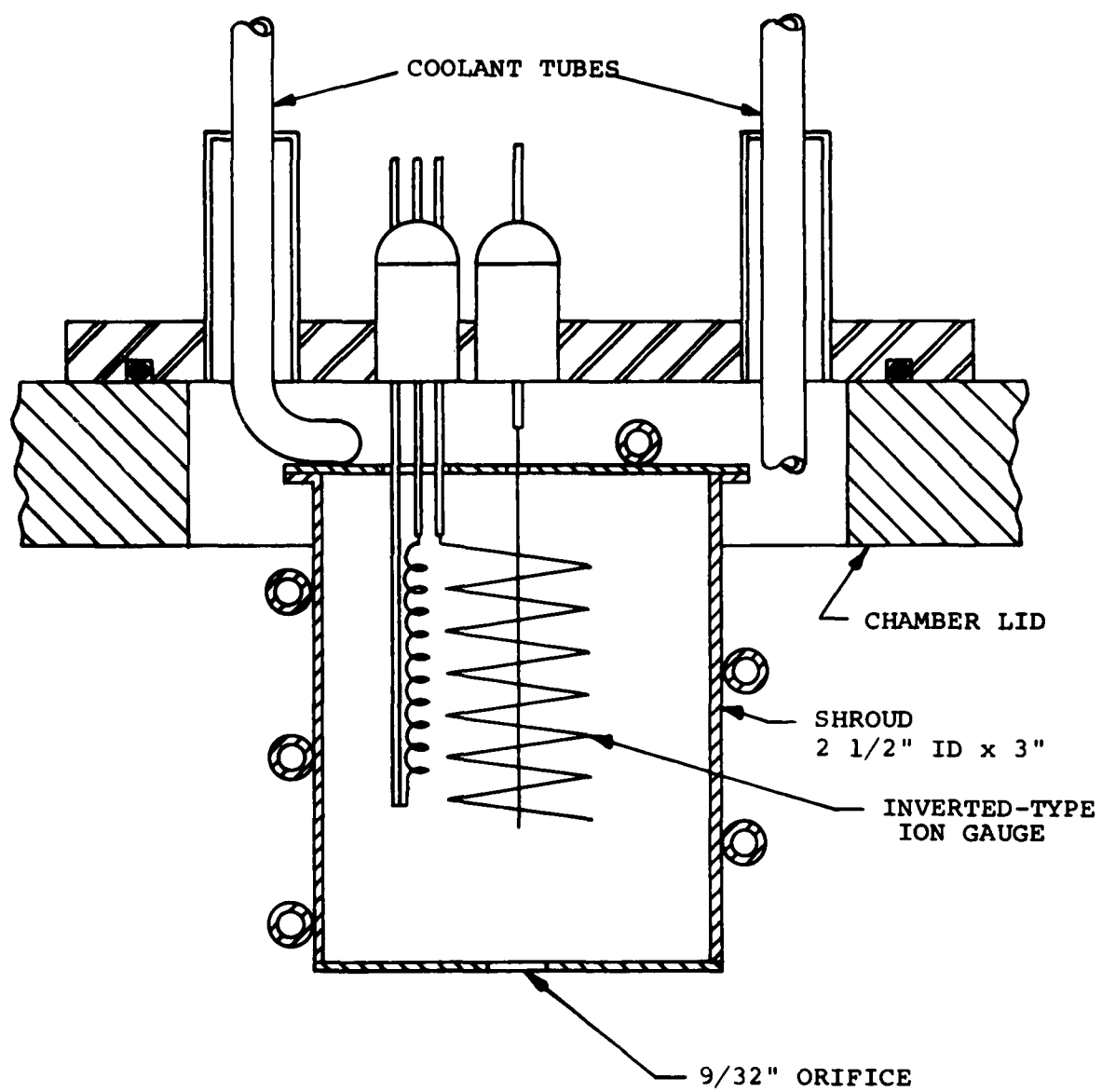


Fig. 3 Experimental Ion Gauge

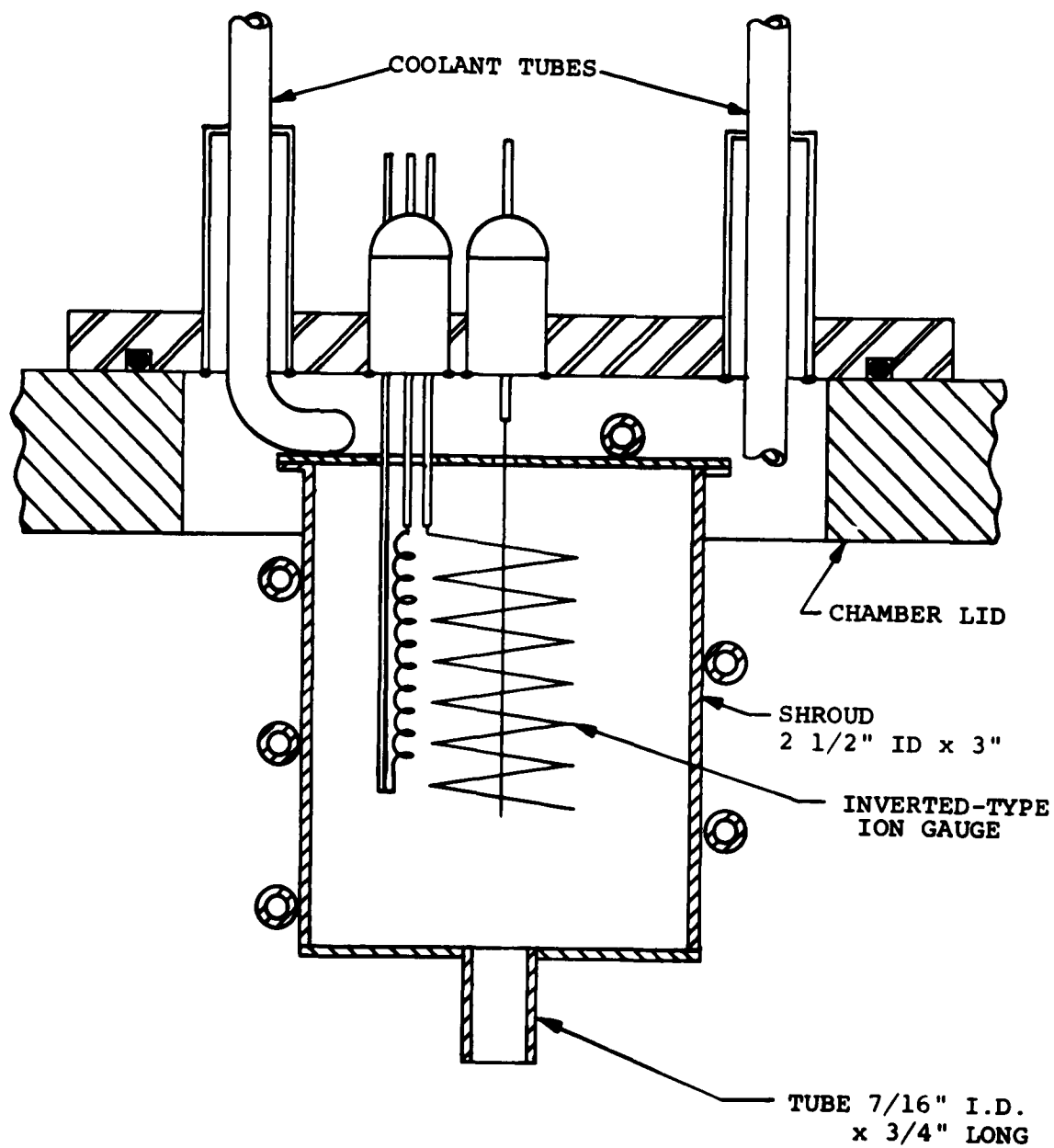


Fig. 4 Experimental Short-Tube Ion Gauge

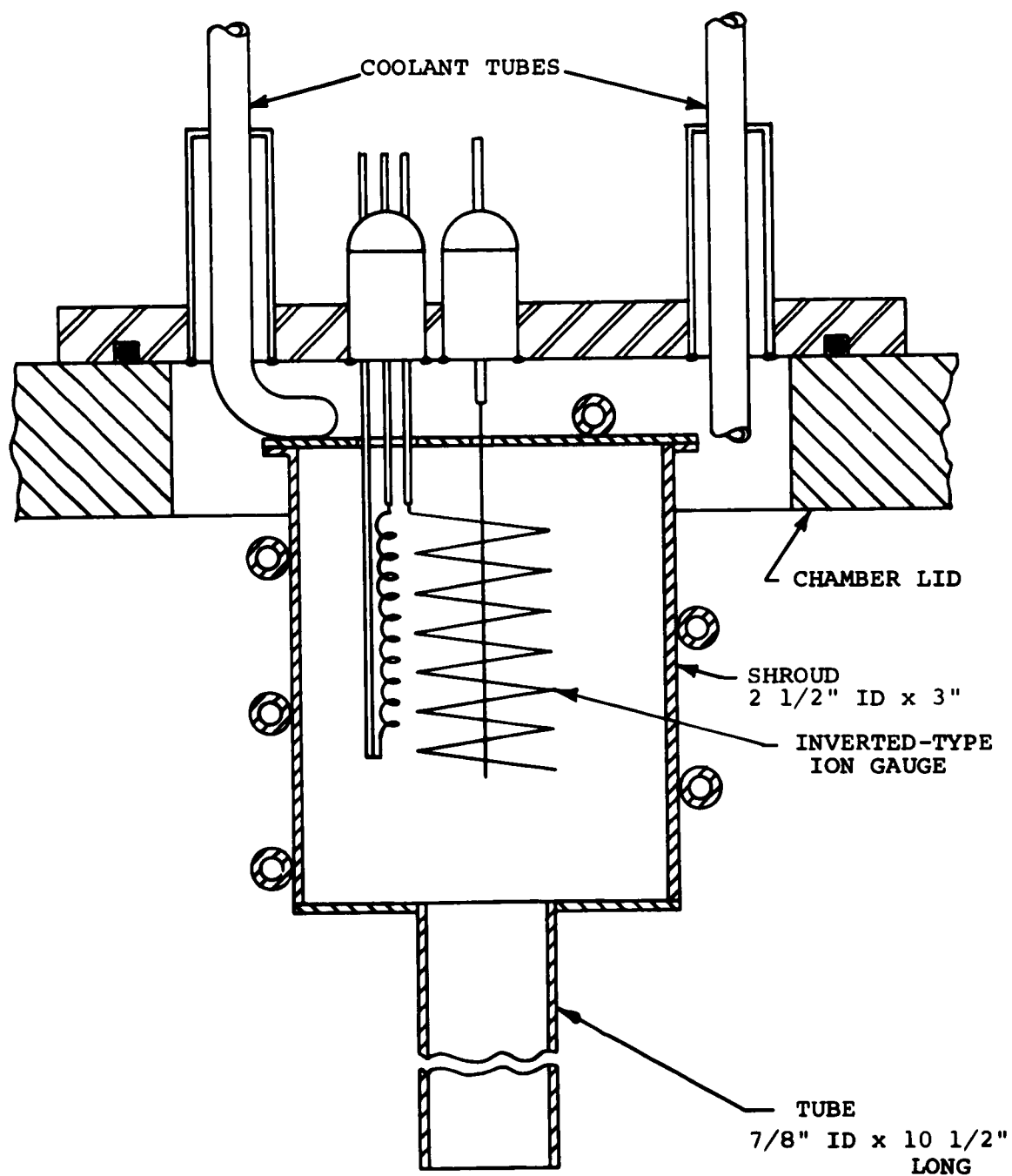
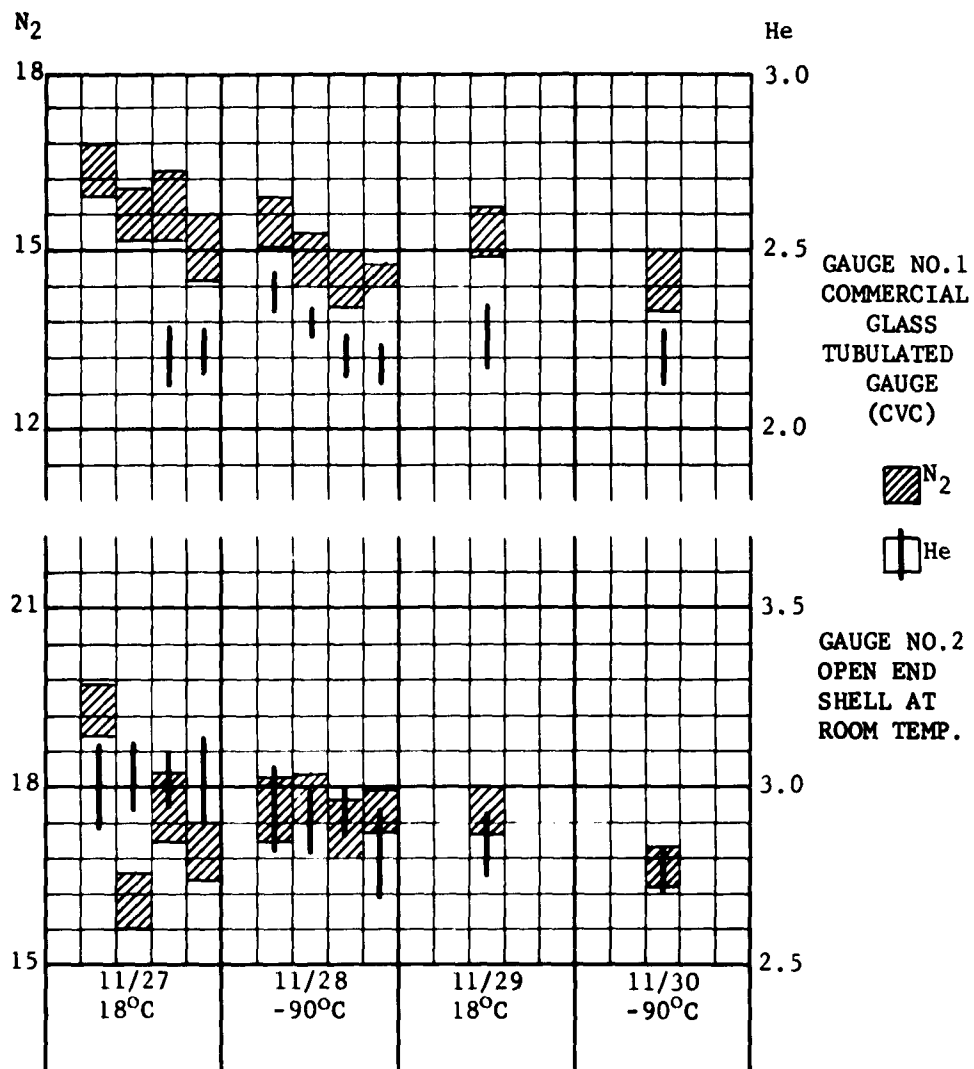


Fig. 5 Experimental Long-Tube Ion Gauge



Fig. 6 Ion Gauges Installed



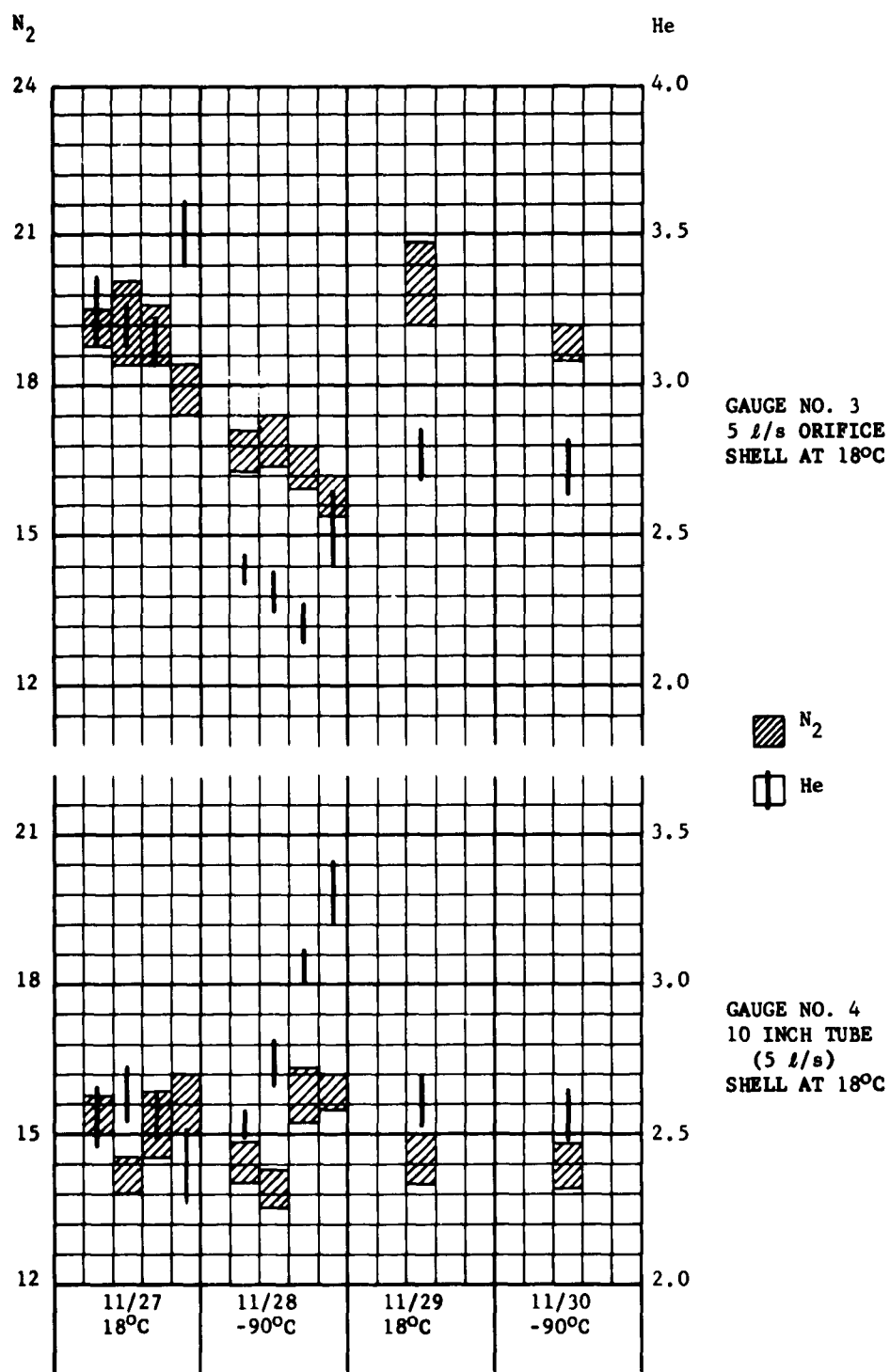


Fig. 8 Effect of Chamber Temperature on Ion Gauge Response - amp x  $10^9$  per torr  
Gas Supply Pressure at 100-microamp Emission

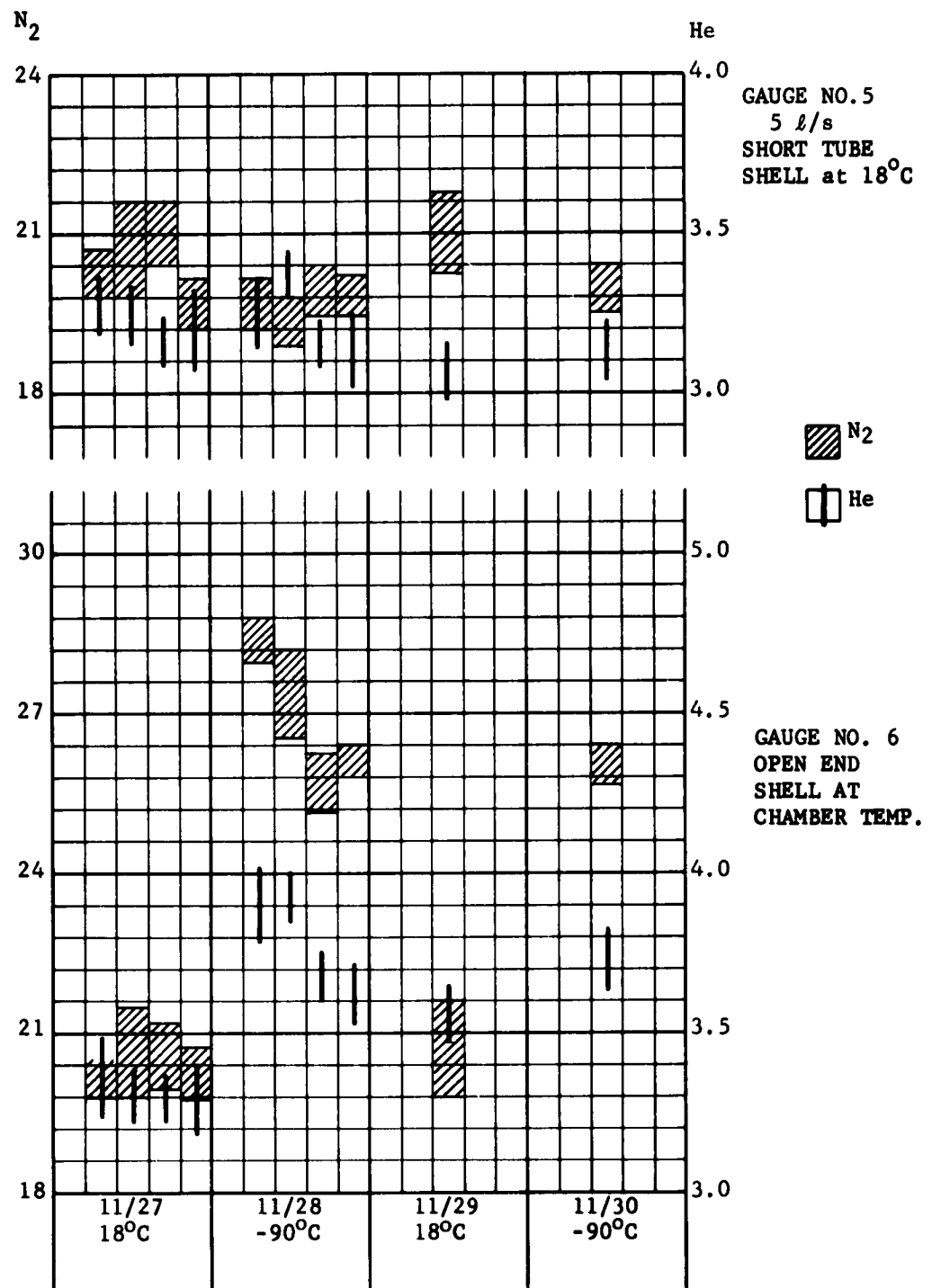


Fig. 9 Effect of Chamber Temperature on Ion Gauge Response — amp x 10<sup>9</sup> per torr  
Gas Supply Pressure at 100-microamp Emission



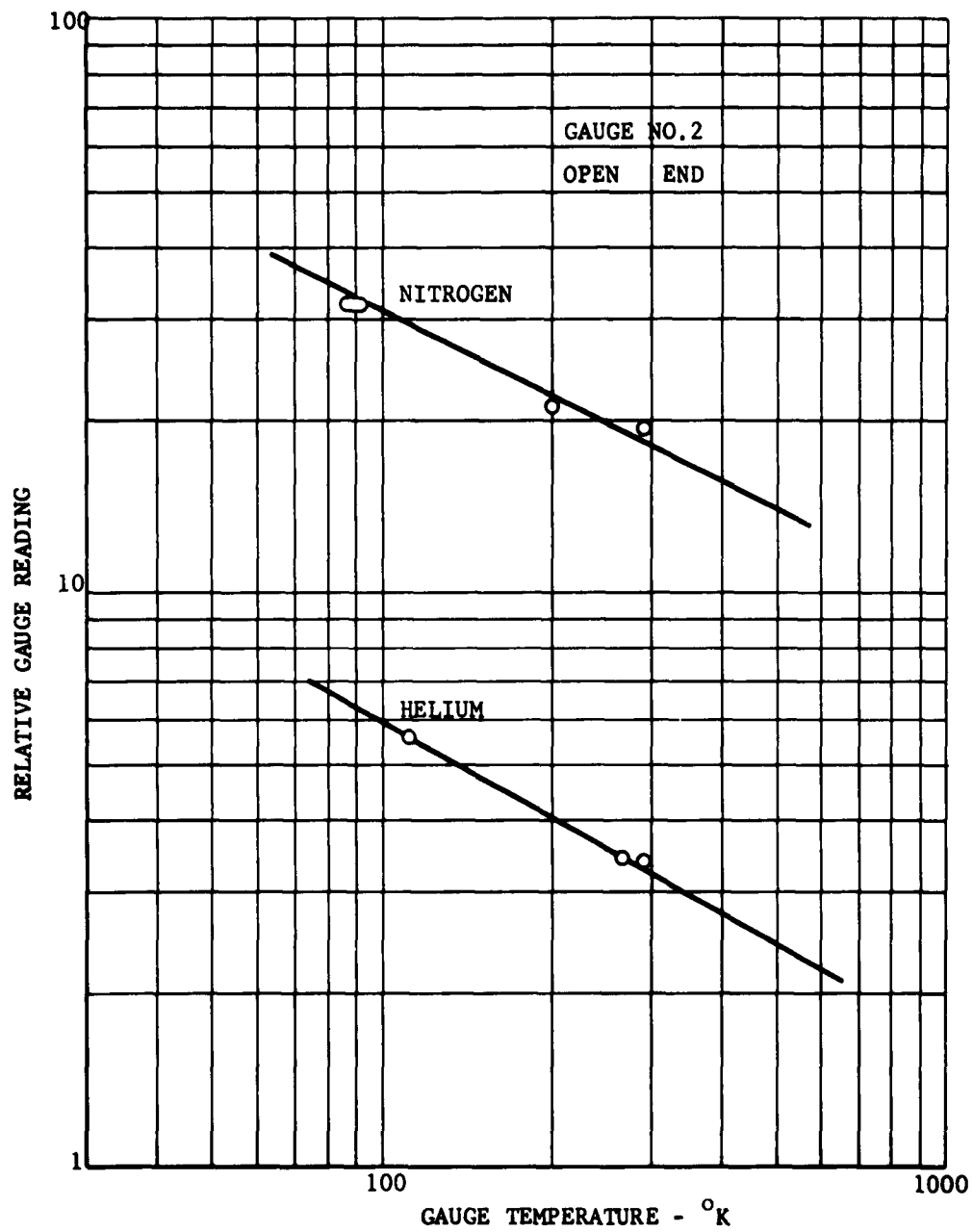


Fig. 10 Effect of Gauge Temperature

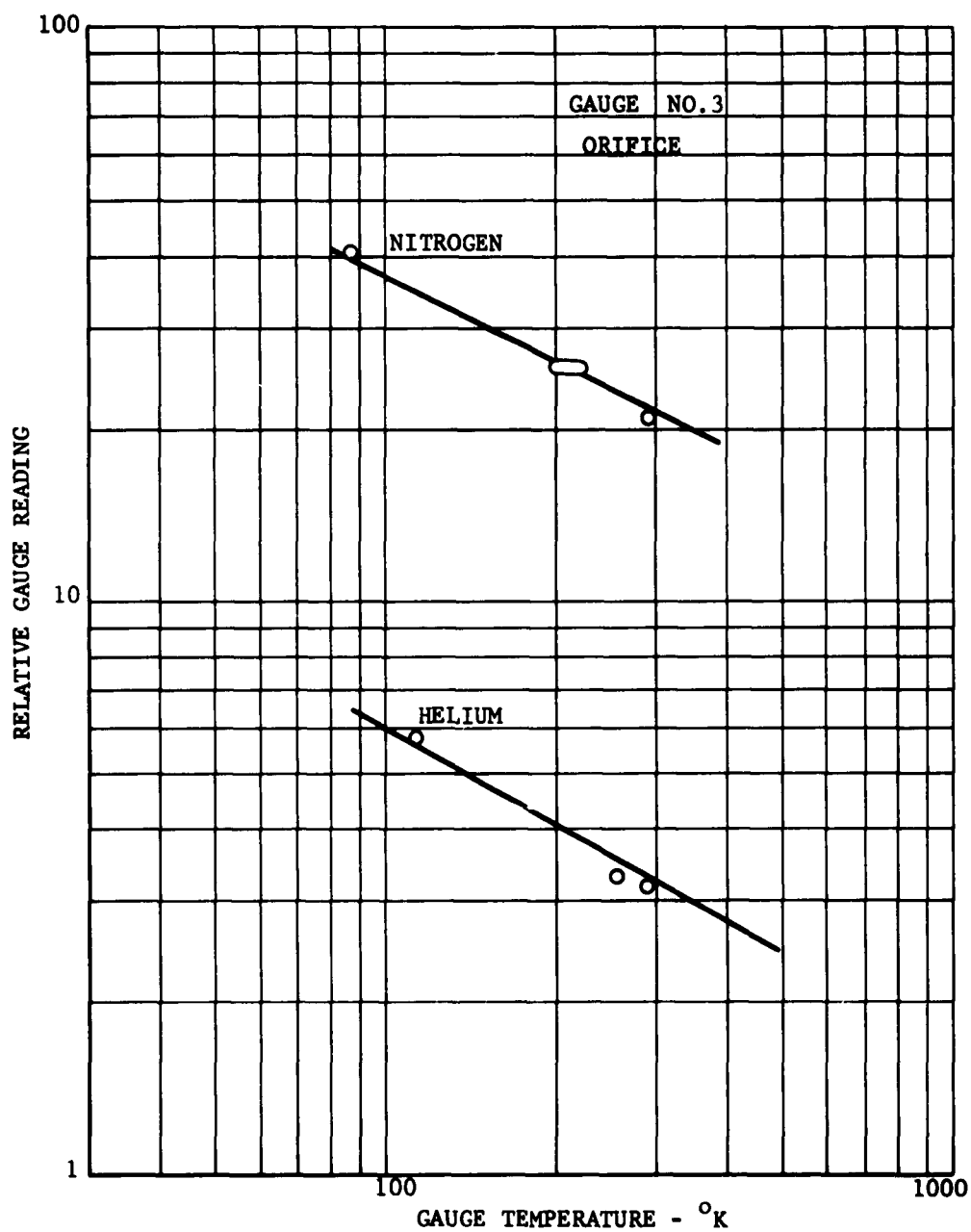


Fig. 11 Effect of Gauge Temperature

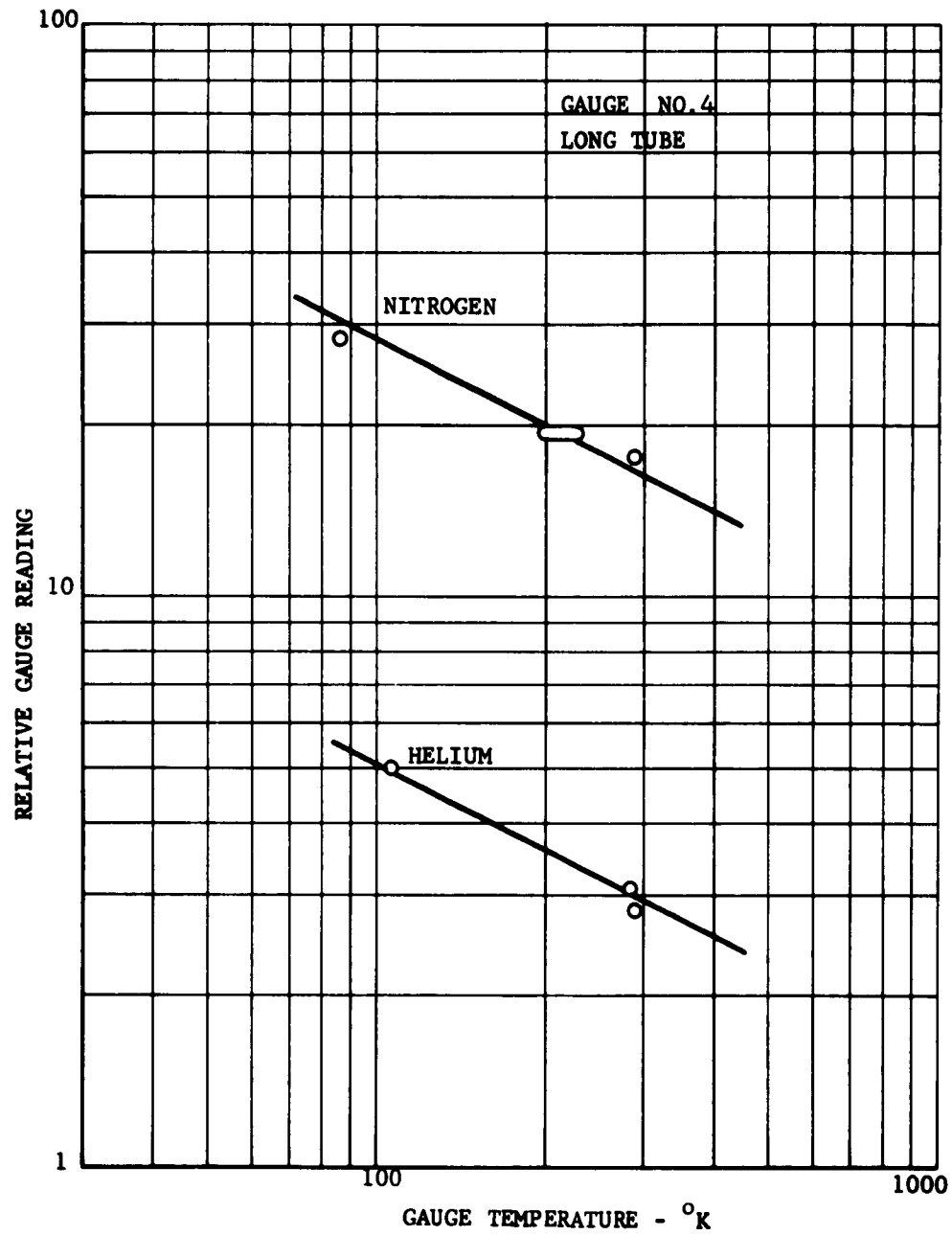


Fig. 12 Effect of Gauge Temperature

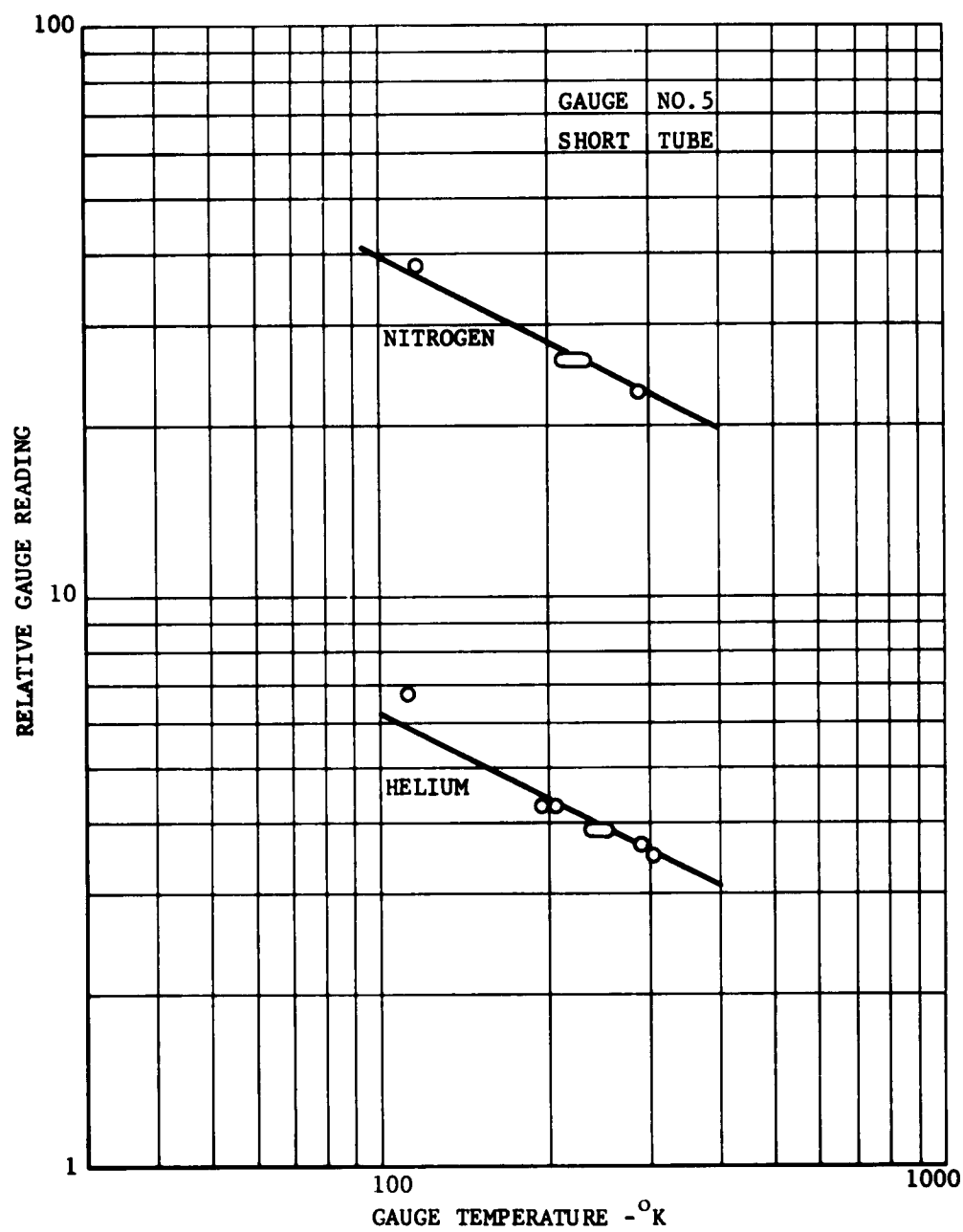


Fig. 13 Effect of Gauge Temperature

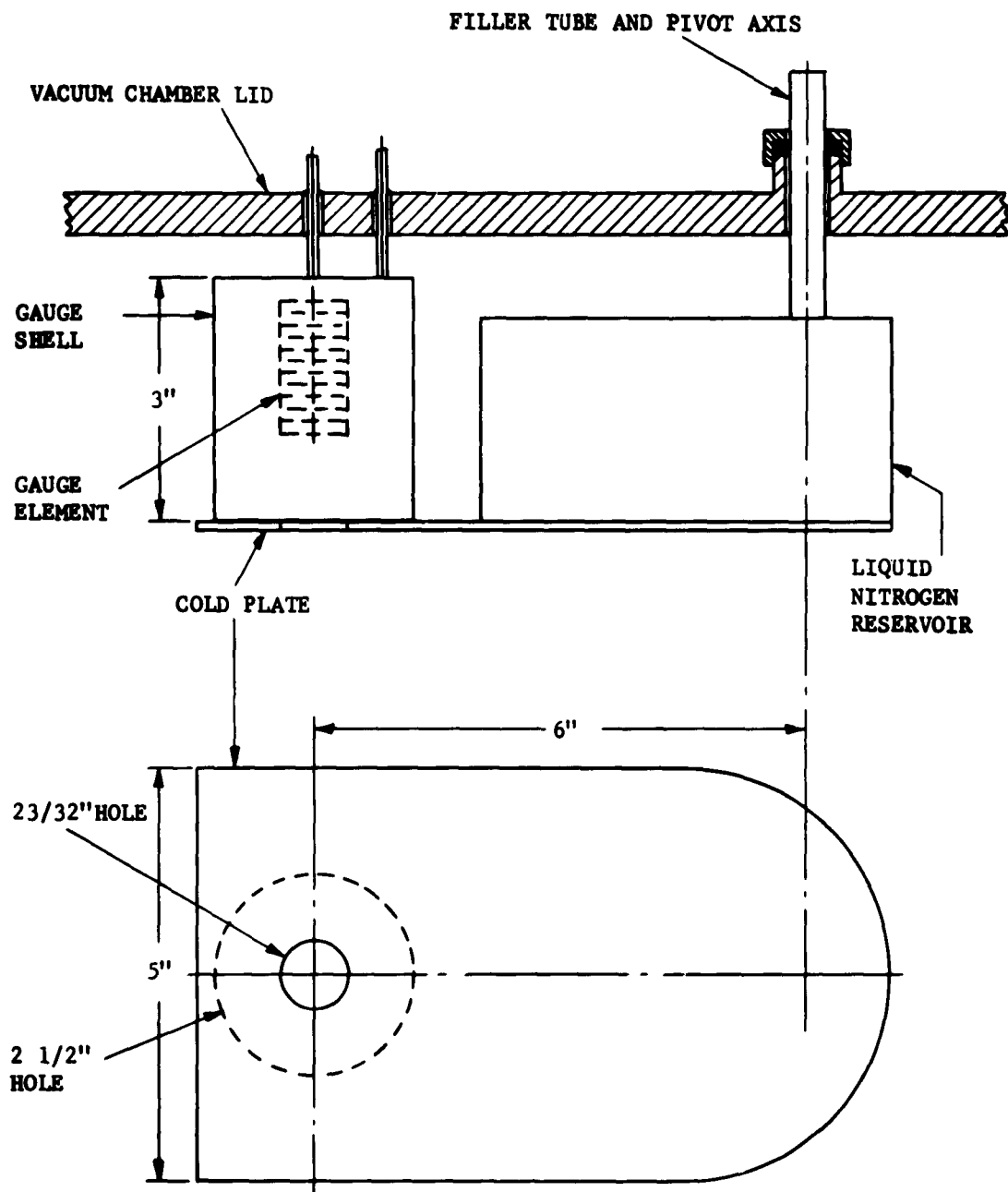


Fig. 14 Experimental Space Simulation Gauge

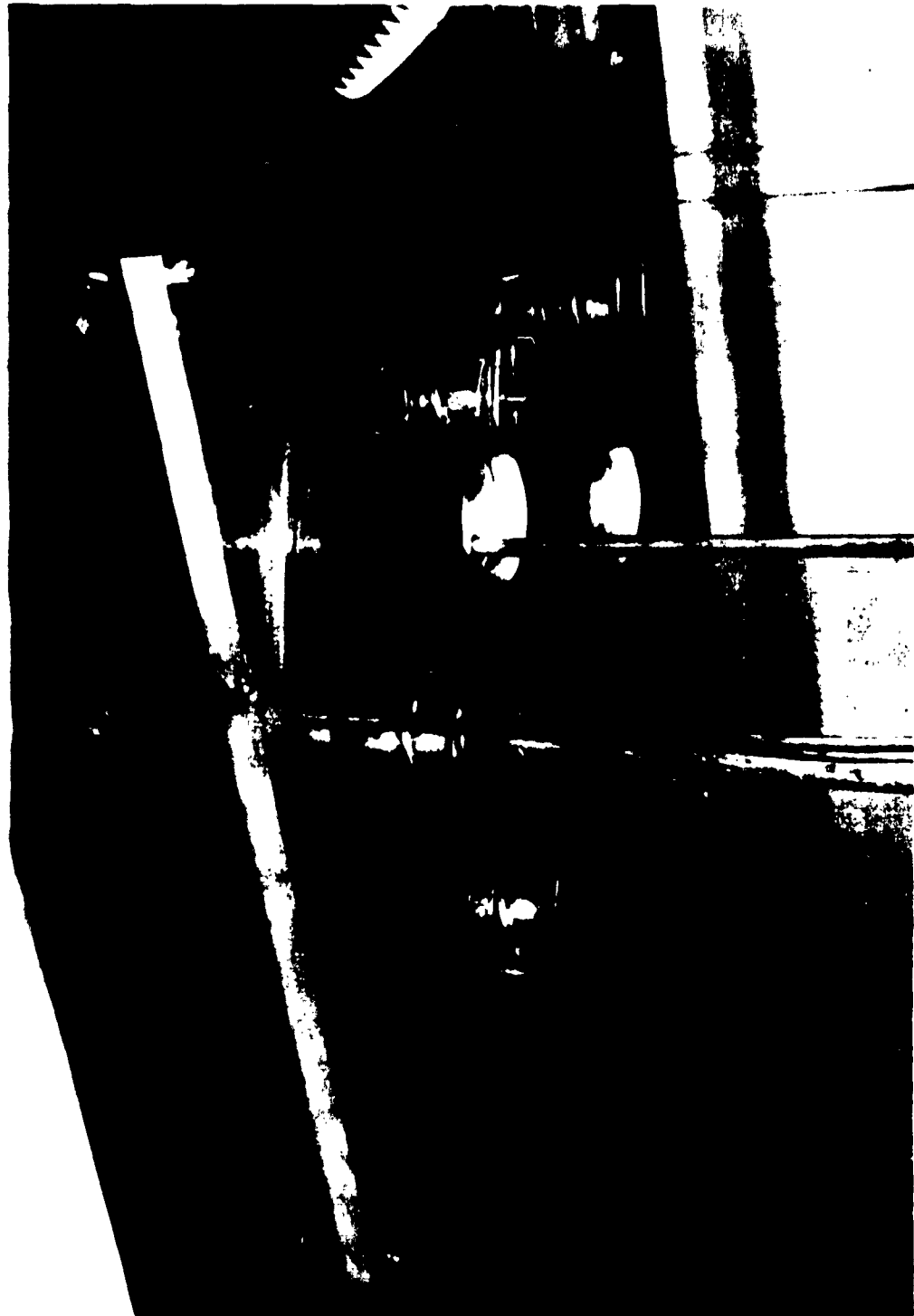


Fig. 15 Space Simulation Gauges Installed

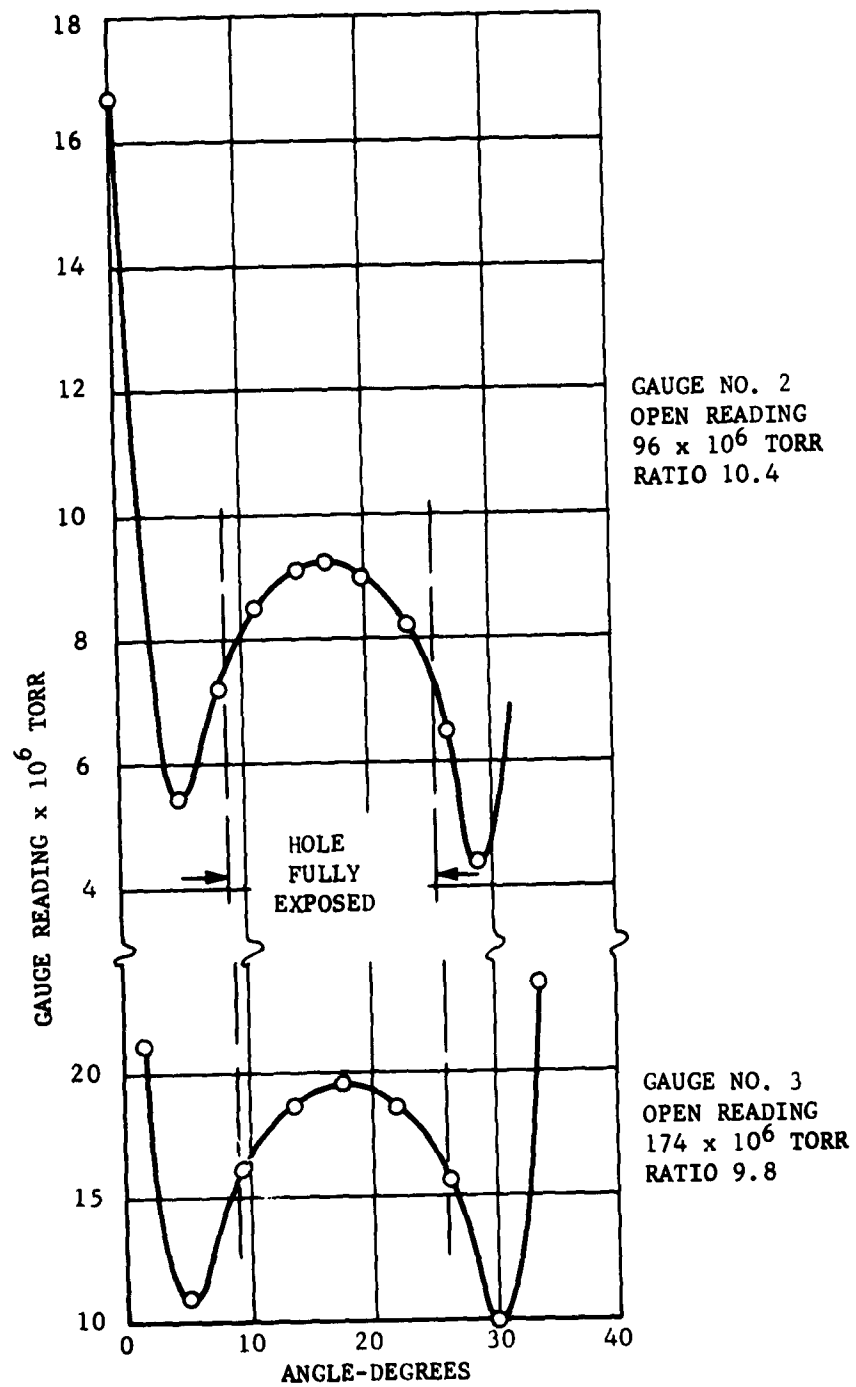






Fig. 16 Space Simulator Gauge Characteristics

|   |   |   |   |
|---|---|---|---|
| <p>Arnold Engineering Development Center<br/>         Arnold Air Force Station, Tennessee<br/>         Rpt. No. AEDC-TDR-63-37. ION GAUGE CHARACTERISTICS IN AN AEROSPACE SIMULATOR. February 1963, 54 p. incl 2 refs., illus., tables. Unclassified Report</p> <p>The purpose of this investigation was to determine the relationship of ion gauge readings to the fundamental gas properties of pressure, density, and molecular incidence rate, and to study a modification of the ion gauge for use in space simulators where directional pressures exist because of large cryogenically-cooled pumping areas. A theoretical analysis of the operation of the ion gauge suggested that a nude gauge senses the density of gas in a vacuum chamber, whereas a tabulated gauge senses the amount of molecular flux incident on the mouth of the tubulation, neither gauge actually measures pressure. Experiments were then conducted with specially constructed gauges in a vacuum</p> | <p>1. Ionization gauges<br/>         2. Cryogenics<br/>         3. Simulators<br/>         4. Space environmental conditions</p> <p>I. AFSC Program Area 850E, Project 7778, Task 777801<br/>         II. Contract AF 40600J-954<br/>         III. General Engineering Lab., General Electric Co., Schenectady, N. Y.<br/>         IV. D. H. Holkeboer and D. J. Santeler<br/>         V. Available from OTS<br/>         VI. In ASTIA Collection</p>   | <p>Arnold Engineering Development Center<br/>         Arnold Air Force Station, Tennessee<br/>         Rpt. No. AEDC-TDR-63-37. ION GAUGE CHARACTERISTICS IN AN AEROSPACE SIMULATOR. February 1963, 54 p. incl 2 refs., illus., tables. Unclassified Report</p> <p>The purpose of this investigation was to determine the relationship of ion gauge readings to the fundamental gas properties of pressure, density, and molecular incidence rate, and to study a modification of the ion gauge for use in space simulators where directional pressures exist because of large cryogenically-cooled pumping areas. A theoretical analysis of the operation of the ion gauge suggested that a nude gauge senses the density of gas in a vacuum chamber, whereas a tabulated gauge senses the amount of molecular flux incident on the mouth of the tubulation, neither gauge actually measures pressure. Experiments were then conducted with specially constructed gauges in a vacuum</p> | <p>1. Ionization gauges<br/>         2. Cryogenics<br/>         3. Simulators<br/>         4. Space environmental conditions</p> <p>I. AFSC Program Area 850E, Project 7778, Task 777801<br/>         II. Contract AF 40600J-954<br/>         III. General Engineering Lab., General Electric Co., Schenectady, N. Y.<br/>         IV. D. H. Holkeboer and D. J. Santeler<br/>         V. Available from OTS<br/>         VI. In ASTIA Collection</p> |
| <p>system where the gas parameters could be varied individually to check the validity of the analysis. The predicted behavior was obtained with both nitrogen and helium, although some anomalous results were seen in the latter case. The modified ion gauge, also known as the Space Simulation Gauge, is a tubulated gauge incorporating a cryogenic pumping surface to reduce the response to the incident flux of condensable molecules as if the flux were reflected from the wall of the space chamber having cryogenic pumping panels. A means of calculating the proper pumping area within the gauge was developed and applied. The ability to produce the intended reduction in sensitivity was experimentally confirmed, and some effects of gauge geometry were explored.</p>   | <p>system where the gas parameters could be varied individually to check the validity of the analysis. The predicted behavior was obtained with both nitrogen and helium, although some anomalous results were seen in the latter case. The modified ion gauge, also known as the Space Simulation Gauge, is a tubulated gauge incorporating a cryogenic pumping surface to reduce the response to the incident flux of condensable molecules as if the flux were reflected from the wall of the space chamber having cryogenic pumping panels. A means of calculating the proper pumping area within the gauge was developed and applied. The ability to produce the intended reduction in sensitivity was experimentally confirmed, and some effects of gauge geometry were explored.</p> | <p>system where the gas parameters could be varied individually to check the validity of the analysis. The predicted behavior was obtained with both nitrogen and helium, although some anomalous results were seen in the latter case. The modified ion gauge, also known as the Space Simulation Gauge, is a tubulated gauge incorporating a cryogenic pumping surface to reduce the response to the incident flux of condensable molecules as if the flux were reflected from the wall of the space chamber having cryogenic pumping panels. A means of calculating the proper pumping area within the gauge was developed and applied. The ability to produce the intended reduction in sensitivity was experimentally confirmed, and some effects of gauge geometry were explored.</p>   |   |



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